# Temperature Forecast Analysis for Summer 2023-24

## September 2024

A report assessing the forecast precision and accuracy of AEMO's operational weather providers in the National Electricity Market from 1 November 2023 to 31 March 2024

# Important notice

## Purpose

This report has been prepared to:

- Give the weather providers used by AEMO an insight into their comparative temperature forecast performance in the National Electricity Market during the 2023-24 summer period.
- Give any intending weather providers information to assess the relative performance of their forecasts.
- Facilitate industry discussion and ongoing improvement of temperature forecast accuracy.

This report is generally based on information available to AEMO as of 31 March 2024 unless otherwise indicated.

## Disclaimer



## Copyright



We acknowledge the Traditional Custodians of the land, seas, and waters across Australia. We honour the wisdom of Aboriginal and Torres Strait Islander Elders past and present and embrace future generations. AEMO Group is proud to have launched its first Reconciliation Action Plan in May 2024 (scan QR code to read).

# Glossary

| Term | Description |
|---|---|
| **Accuracy versus precision** | Accuracy refers to how close an actual temperature measurement is to the forecast value. Precision is the frequency at which a forecast error is reproduced. Therefore, a set of forecast outcomes could be precise in that its errors fall within a narrow range, and a set of forecast outcomes are both accurate and precise when that small range of errors are close to the actual measurement. |
| **Dew point temperature** | The temperature to which air must be cooled to produce condensation (dew), which represents how much moisture is in the air. |
| **Dry-bulb temperature** | The temperature of air measured by a thermometer freely exposed to the air but shielded from radiation and moisture. |
| **Electricity demand (operational demand)** | The sum of scheduled, semi-scheduled, and significant non-scheduled generation connected to the National Electricity Market (NEM). |
| **Forecast error (°C)** | Forecast temperature minus actual temperature. |
| **Mean Absolute Error (MAE)** | The calculated average of the absolute (unsigned) forecast error. Mean absolute error is only used in reference to temperature forecast error (°C) in this report. |
| **Relative humidity** | Measure of the amount of water vapour in the air compared with the total needed for saturation at a given temperature. |
| **Rolling forecast horizon** | A forecast that is always created X hours ahead of the actual observation. For example, for a 4 hour ahead rolling forecast horizon, the observation at 12:00 pm was forecast at 8:00 am, and the observation at 4:00 pm was forecast at 12:00 pm. |

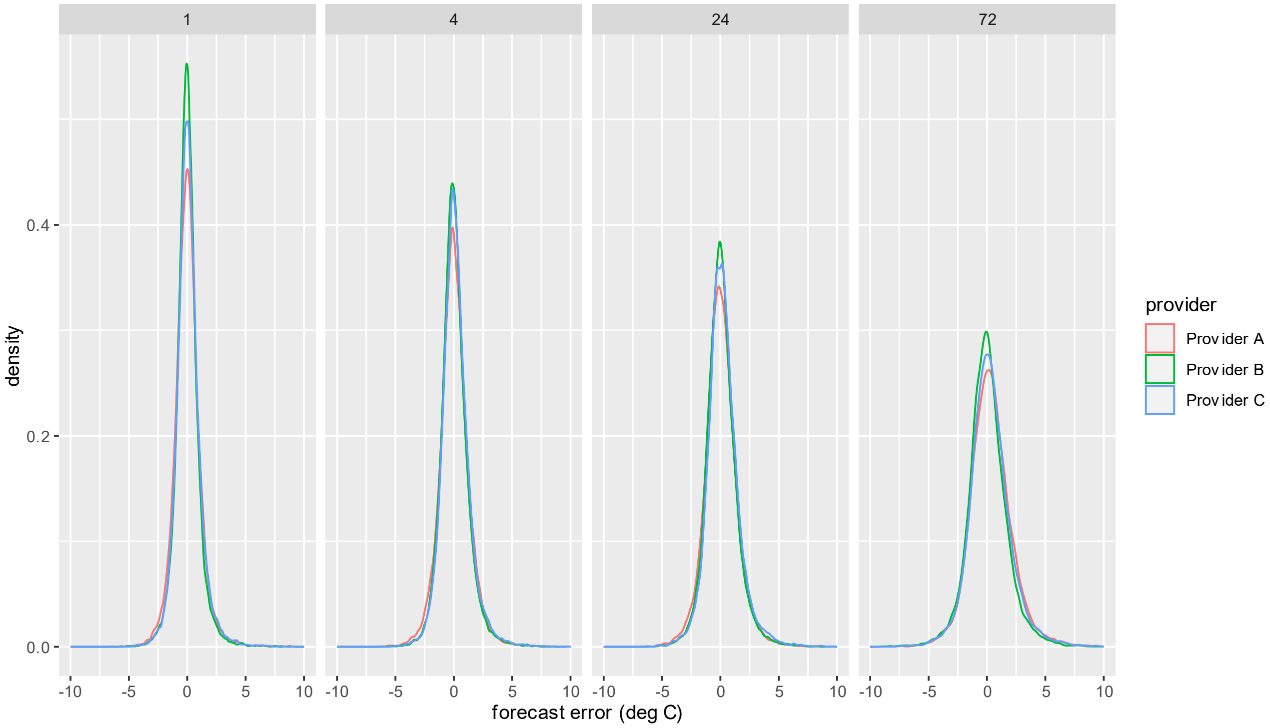
# Executive summary

This report examines the hourly temperature forecast performance of AEMO's weather service providers in the National Electricity Market (NEM) from 1 November 2023 to 31 March 2024 (referred to as "summer 2023-24" in this report). The report studies temperature forecast performance using accuracy and precision assessment at the 1, 4, 24, and 72 hours ahead (HA) rolling forecast horizons at the major weather stations used by AEMO's Demand Forecasting System (DFS). It has been prepared as a resource for weather providers to benchmark their performance, and to facilitate discussion about developments and ongoing improvements of weather forecast performance to support system operation and the broader energy industry.

Key findings from the summer 2023-24 performance analysis of AEMO's three weather forecast providers (Figure 1) are:

- **Provider A**
  - Forecast accuracy and precision were overall the lowest among the three providers at all forecast horizons including the highest intraday mean absolute error (MAE) at all studied weather stations.
  - Forecast accuracy and precision across all assessed forecast horizons was comparable to summer 2022-23 performance for all temperatures except at the 24 HA forecast horizon.
  - A marginal decrease in performance when forecasting the top 10% of temperatures compared to summer 2022-23 at all forecast horizons.
  - Overall, forecast accuracy was comparable to the other providers however precision was the lowest at all forecast horizons, and intraday mean absolute error (MAE) was the highest at all studied weather stations.
- **Provider B**
  - Forecast accuracy and precision were the overall highest among all providers at all forecast horizons.
  - Significant improvements at the 1 HA forecast horizon compared to summer 2022-23 and the highest performance at this horizon of all providers.
  - Highest overall performance among all providers when forecasting the top 10% of temperatures at all forecast horizons, except at the 24 HA forecast horizon, when it tended to under-forecast extreme temperatures at most assessed weather stations.
  - Overall lower performance at Archerfield AP compared to summer 2022-23, however performance at the top 10% of temperatures had improved, proving beneficial on extreme hot days.
- **Provider C**
  - Highest accuracy and precision when forecasting the top 10% of temperatures at the 24 HA forecast horizon.
  - Overall significant improvement in performance at Archerfield AP when forecasting the top 10% of temperatures at the 24 HA forecast horizon.
  - Forecast precision improved at the 1 HA forecast horizon compared to summer 2022-23 and similarly high performance at the 4 HA forecast horizon to Provider B.

**Figure 1 Summer 2023-24 performance across all major weather stations and temperatures**




This report also includes a case study to discuss the impacts of summer heat and humidity on demand and rooftop PV forecast performance on a peak demand day in Queensland during January 2024.

AEMO will use this report to aid operational decision-making and draw attention to potential areas of improvement in the weather forecasting industry. This will support existing initiatives between AEMO and the weather forecasting industry, including:

- Redevelopment of AEMO's Projected Assessment of System Adequacy (PASA) to be probabilistic and include weather uncertainty margins in reserve calculations.
- Establishment of new weather observation stations located with renewable energy zones (REZs) near remote variable renewable energy (VRE) generators and in metropolitan heat islands to support weather forecasting.
- Accessing a range of probabilistic weather forecasts from providers to improve situational awareness and better represent extreme weather risk and operational envelopes in demand, rooftop PV, and VRE forecasts.
- AEMO's NEM Local Temperature Alerts process, recently updated in October 2023[1], and updates to AEMO's abnormal conditions reclassification criteria[2] to include actions for severe weather phenomena.
- Considering a fourth provider which utilises AI-powered models with higher spatial and temporal resolution than conventional models to forecast wind speed, irradiance, and temperature for energy forecasts.

[1] NEM Local Temperature Alerts process: https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/projected-assessment-of-system-adequacy/nem-local-temperature-alerts#:~:text=When%20forecast%20temperatures%20for%20these,in%20their%20dispatch%20offers%20or.

[2] See section 8 in AEMO's Power System Security Guidelines: https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/power_system_ops/procedures/so_op_3715-power-system-security-guidelines.pdf?la=en

# Contents



# Figures

# 1 Introduction

This report examines the hourly temperature forecast performance of AEMO's three weather service providers in the National Electricity Market (NEM) from 1 November 2023 to 31 March 2024[3] (referred to as "summer 2023-24" in this report).

It aims to highlight the differences in forecasting performance between summer 2022-23 and 2023-24, while also drawing new performance insights from the summer 2023-24 period. It is part of a series of biannual *Temperature Forecast Analysis* reports available on AEMO's website for summer and winter periods since 2018[4].

This report has been prepared as a resource for existing and intending weather service providers to benchmark their forecast performance, and to facilitate discussion and ongoing improvement of temperature forecast performance to support power system operation in the NEM and the broader energy industry. It includes a case study to discuss the impact of late summer heat on temperature forecast performance in January in Queensland.

The providers in this report have been anonymised as Provider A, B, and C (consistent with previous reports) and their temperature forecast accuracy and precision analysed at the 1, 4, 24, and 72 hours ahead (HA) rolling forecast horizons.

The weather stations analysed in this report are Adelaide West Terrace (WT) (South Australia), Archerfield Airport (AP) (Queensland), Bankstown AP (New South Wales), Hobart AP (Tasmania), Melbourne AP (Victoria), Melbourne Olympic Park (OP) (Victoria), Penrith Lakes (New South Wales) and Sydney AP (New South Wales). These are the main weather stations used by the NEM Demand Forecasting System (DFS) and as such they have the largest influence on demand forecasts for their respective NEM regions.

Within the DFS, the New South Wales, Victoria and South Australia regions are each forecast as a single area. The Queensland region forecast is an aggregate of forecasts for the Northern, Central and Southern areas. The Tasmania region forecast is an aggregate of the Northern and Southern areas.

## 1.1 Sensitivity of electricity demand to temperature

Figure 2 shows the absolute and proportional change in operational demand with reference to temperature for each NEM region, to provide context for the results in this report[5].

The performance of a temperature forecast must be understood with reference to its operational impact on electricity demand. The performance of temperature forecasts is most critical for operational demand forecasting when demand is high, generation reserves are low, or when a small change in temperature results in a large change in demand. These conditions are often encountered on hot summer and cold winter days, meaning it is important for weather providers to produce accurate and precise temperature forecasts on these days.

Electricity demand has different temperature sensitivity in each NEM region due to factors such as climate and the mix of residential, commercial, and industrial load. In addition, the same demand forecast error will have different

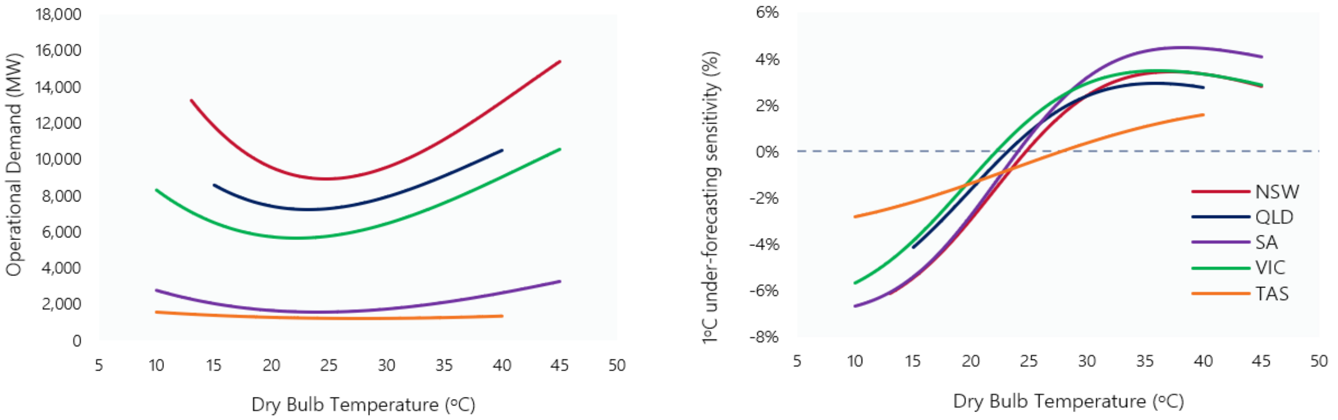
[3] All analysis refers to time in Australian Eastern Standard Time (AEST).

[4] Previous reports available at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/load-forecasting-in-pre-dispatch-and-stpasa.

[5] This analysis shows the relationship of maximum daily dry bulb temperature and maximum daily operational demand on weekdays between 1 January 2018 and 31 March 2023. Temperature readings were taken from primary weather stations for demand forecasting in each region; New South Wales – Bankstown AP, Queensland – Archerfield AP, Victoria – Melbourne OP, South Australia – Adelaide WT, Tasmania – Hobart AP.

operational impacts for different regions. Since each region has limited local generation and interconnector capacity, percentage changes in demand must be understood in conjunction with absolute demand changes.

**Figure 2 Weekday maximum daily operational demand against maximum dry bulb temperature (left) and the percentage change in operational demand for a 1°C under-forecasting error (right) for each NEM region.**




## 1.2 Load growth in the NEM

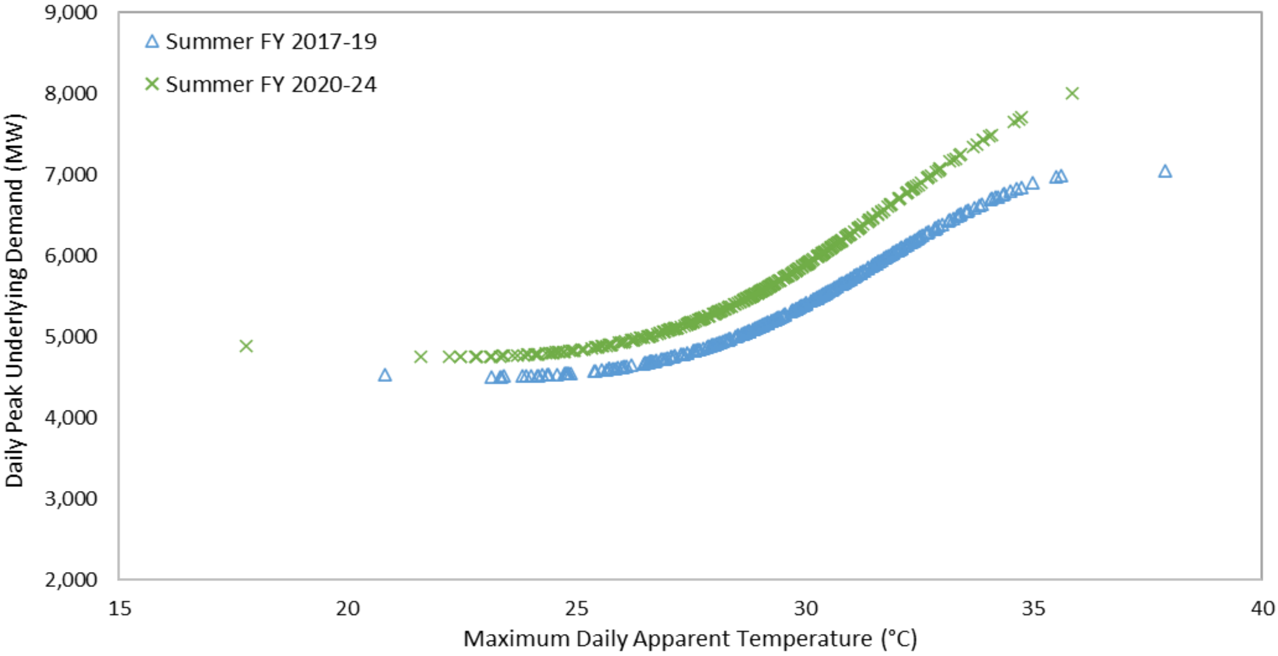
Since early 2020, there has been an increase in the proportion of people working from home. This in turn has elevated residential electricity load and increased the temperature sensitivity of demand overall, particularly at extreme temperatures when there are significant heating and cooling loads.

In addition to increased temperature sensitivity, underlying load growth in select NEM regions has become apparent.

Figure 3 demonstrates this for southern Queensland by showing daily maximum underlying demand[6] for weekdays in summer between 2017 and January 2024 for different maximum daily apparent temperatures averaged across the weather stations used in the DFS. Compared to days between 2017-19, there is an apparent increase in underlying demand for all temperatures during the 2020-24 summers, with a greater magnitude, or flex, at higher temperatures.

[6] Underlying demand is an estimate of total consumption calculated as the sum of operational demand and distributed rooftop PV.

**Figure 3 Summer weekday maximum daily underlying operational demand against maximum daily apparent temperature at Archerfield AP for southern Queensland**




Analysis was also performed for other mainland NEM regions, with an increase in demand observed, however this was only material at higher temperatures for New South Wales and Victoria, and no identification of underlying load growth in South Australia.

## 1.3 Humidity impact on electricity demand

Humidity's impact on electricity demand is felt most when it is combined with high dry bulb temperatures. In warm, humid weather, moisture in the air can impede the body's ability to cool down, making people feel hotter for longer. This in turn drives demand for electricity demand through air-conditioning. Also, when humidity levels are high, it negatively affects the cooling efficiency of air-conditioning units, meaning they consume more electricity.

The weather concept that best describes this relationship between humidity and the need for cooling is the dew point, which is the temperature to which air must be cooled to produce condensation (dew). Dew point is related to the quantity of moisture, while relative humidity expresses how close the air is to saturation. Because of its proportional relationship to fluctuating temperature, relative humidity doesn't provide suitable guidance on how much moisture is available at a specific location.

The conditions someone is accustomed to, as well as their metabolism, vary the way dew point is experienced. For a dew point for those living in Brisbane that may feel uncomfortable, that same dew point would feel considerably more oppressive in Melbourne, where people are less acclimatised to this type of weather. An example of an index of how an average person may feel at a certain dewpoint in Brisbane's climate can be found in Table 1 below[7].

[7] The weather concept of dew point provides a gauge of the impact of the combination of temperature and humidity and helps infer what the conditions may feel like. For more information on dew point, see https://media.bom.gov.au/social/blog/1324/feeling-hot-and-bothered-its-notthe-humidity-its-the-dew-point/.

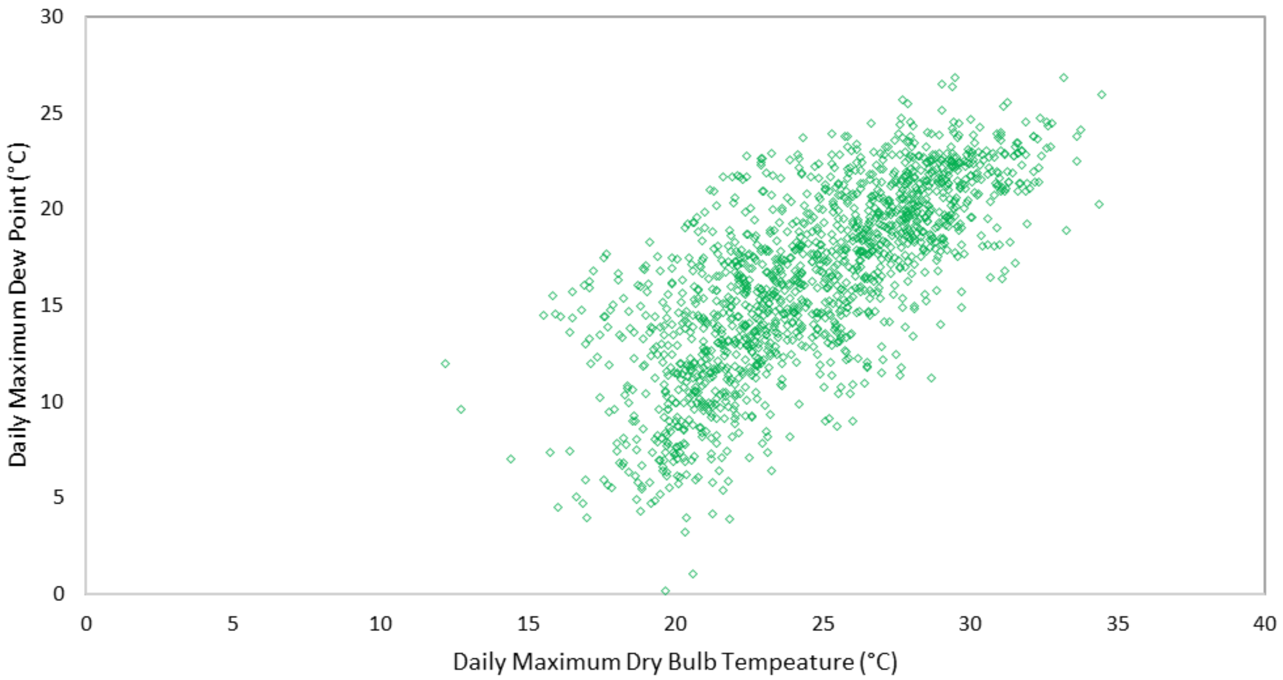
**Table 1 Dew point index for southern Queensland**

| Dew point temperature (°C) | How it feels | Dew point bucket |
|---|---|---|
| **> 24** | Oppressive, uncomfortable for most, possible heat stress issues | Extreme |
| **20 - 24** | Muggy, quite uncomfortable | High |
| **15 - 20** | Starting to feel muggy, though still comfortable for most | Moderate |
| **10 - 15** | Comfortable | Low |
| **< 10** | Dry | Minor |

The accuracy of humidity forecasts is most critical for operational demand forecasting when temperatures and therefore demands are high. These conditions are typically only encountered on hot summer days in the northern states such as Queensland, although specific weather patterns can also push high humidity into the southern parts of Australia.

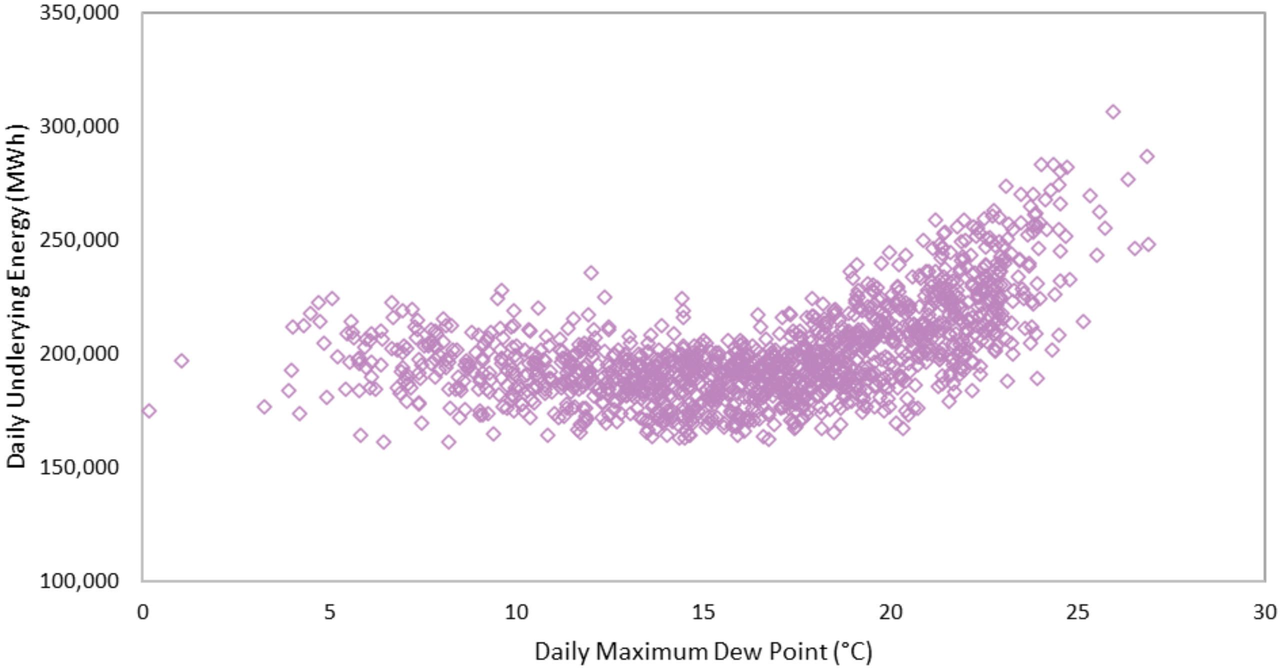
For this analysis, both dry bulb temperature and dew point used are weighted averages across the weather stations used in the DFS. The correlation between dry bulb temperature and dew point can be seen in Figure 4 where generally higher maximum daily dry bulb temperatures coincide with higher maximum daily dew points, however there is a spread in the dew points for a given dry bulb temperature which has an influence on how a person feels and therefore their behaviour.

**Figure 4 Maximum daily dew point against maximum daily temperature for southern Queensland**



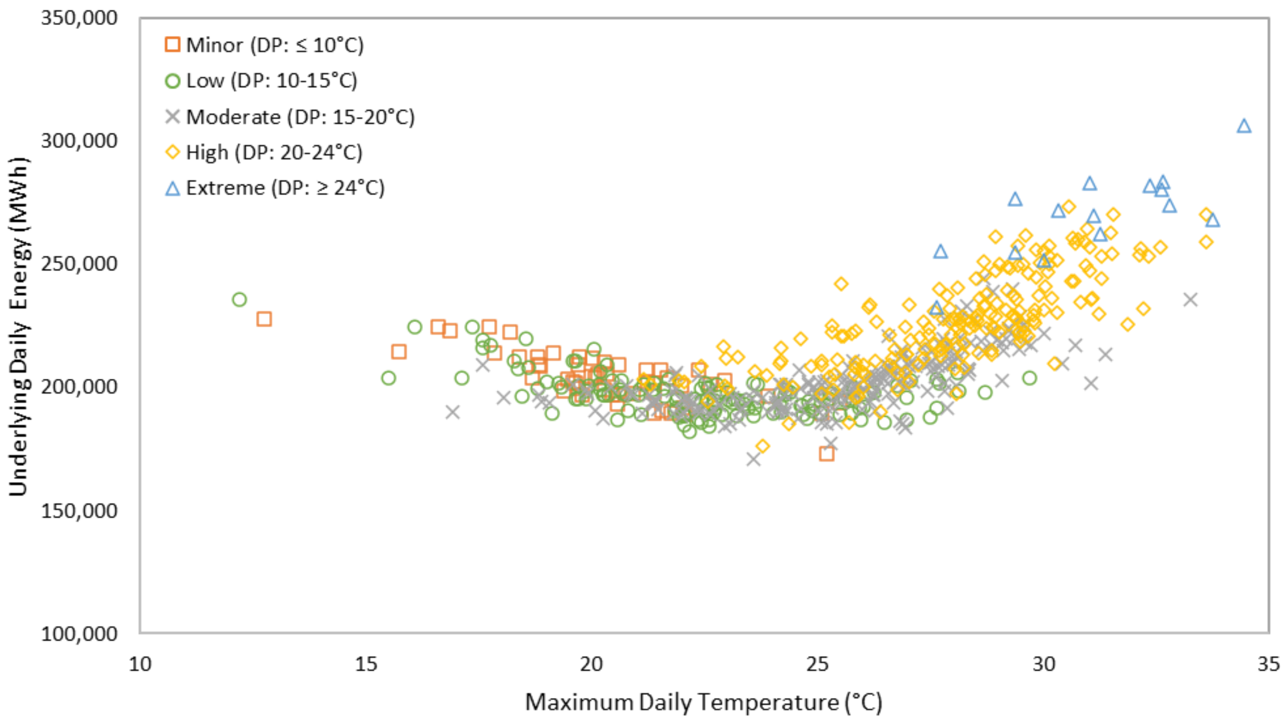

The relationship between maximum daily dew point and underlying daily energy is displayed in Figure 5, where a flex in the underlying energy is observed when dew points start to increase above 20°C, as this is the point where people start to feel uncomfortable and increase their electricity usage.

**Figure 5 Maximum underlying daily energy against maximum daily dew point for southern Queensland**




Based on Figure 6, for different dew point buckets, underlying daily energy is generally higher for higher dew points. For dry bulb temperatures up to 25°C for all dew point buckets, there is a tighter distribution of underlying daily energy. Dry bulb temperatures greater than 25°C start to show a wider distribution of underlying daily energy, with the spread becoming larger as dew point increases for a given dry bulb temperature. As dry bulb temperatures get higher, it's uncommon to see low dew points, and therefore for dry bulb temperatures greater than 30°C most observations are in the high to extreme dew point buckets and correspond to the highest levels of underlying daily energy.

**Figure 6 Weekday maximum underlying daily energy against maximum daily dry bulb temperature for different dew point buckets for southern Queensland**



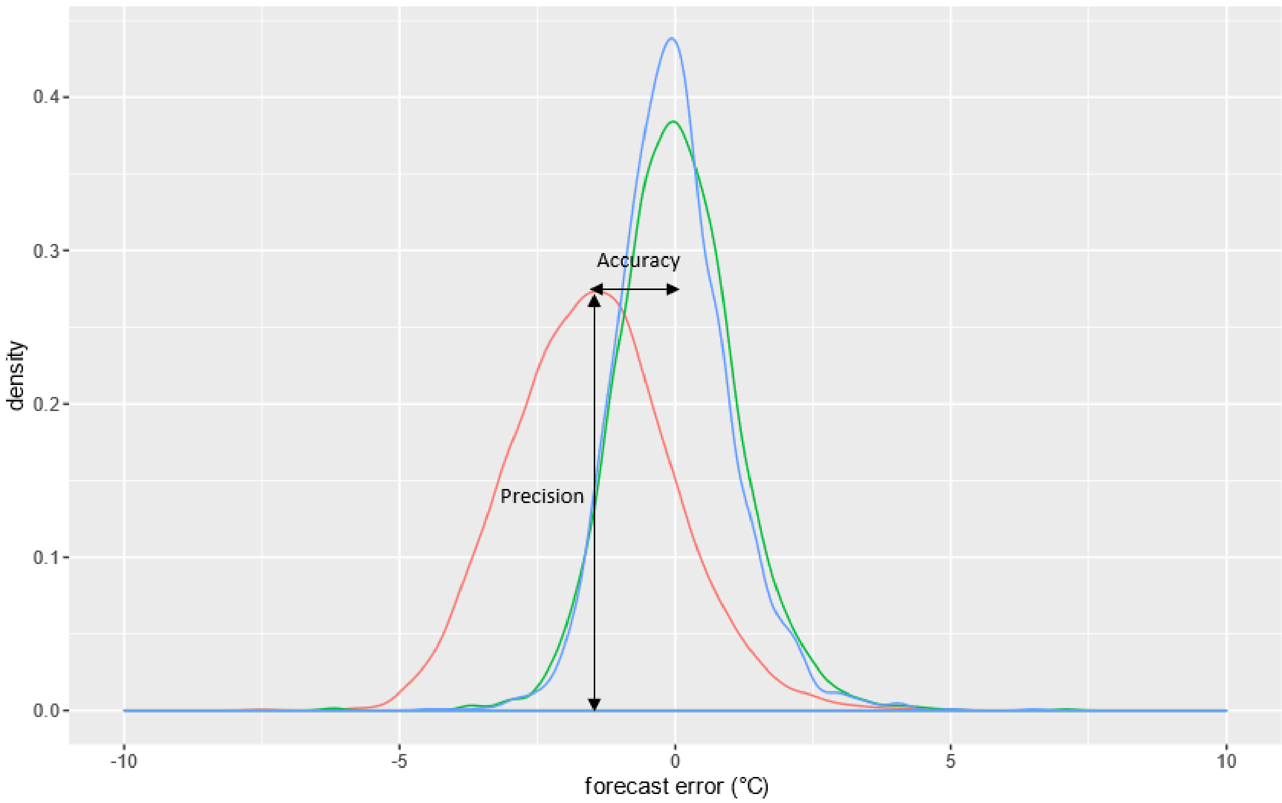
# 2 Summer forecast performance

This section contains a selection of temperature forecasting performance insights for summer 2022-23 in the NEM. Results supporting major insights are included in this section, with additional results in the appendices. This report studies temperature forecast performance at the 1, 4, 24, and 72 HA rolling forecast horizons.

Many of the results in this section and in A1 are displayed as error density plots like Figure 7 below. These figures can be interpreted as follows:

- The **x-axis shows forecast error**. Positive values indicate over-forecasting (the forecast temperature exceeded the actual temperature), and negative values indicate under-forecasting (the forecast temperature was lower than the actual temperature).
- The **y-axis shows error density**. This reflects the relative rate of a forecast error occurring. For each forecast error, the error density will be between 0 and 1, and the area under each curve equals 1.
- The **height of the error density peak captures the level of forecast precision**. The higher the peak, the greater the forecast precision and the smaller the expected deviation from the level of error. In Figure 7, the forecast distribution (blue) has the highest precision, and the forecast distribution (red) has the lowest precision.
- The **position of the peak captures the forecast accuracy** with respect to a forecast error of zero. The further the peak is from zero error, the lower the accuracy, and the larger the tendency for over- or under-forecasting on average. In Figure 7, the forecast distribution in red is less accurate than the forecast distributions in green and blue.

**Figure 7 Accuracy and precision in the error density plot**



In addition, Appendix A2 contains intraday mean absolute error (MAE) profiles for the weather stations assessed in the report, where forecast performance is provided for each hour of the day and for each provider. Appendix A3 contains profiles for the net count of forecast error direction, which show the net number of days where each hourly interval was either negative (actuals greater than forecast) or positive (actuals less than forecast) assessed over the warmest 10% of days. The charts in Appendix A2 and A3 do not explicitly feature in the main report.

## 2.1 Overall performance

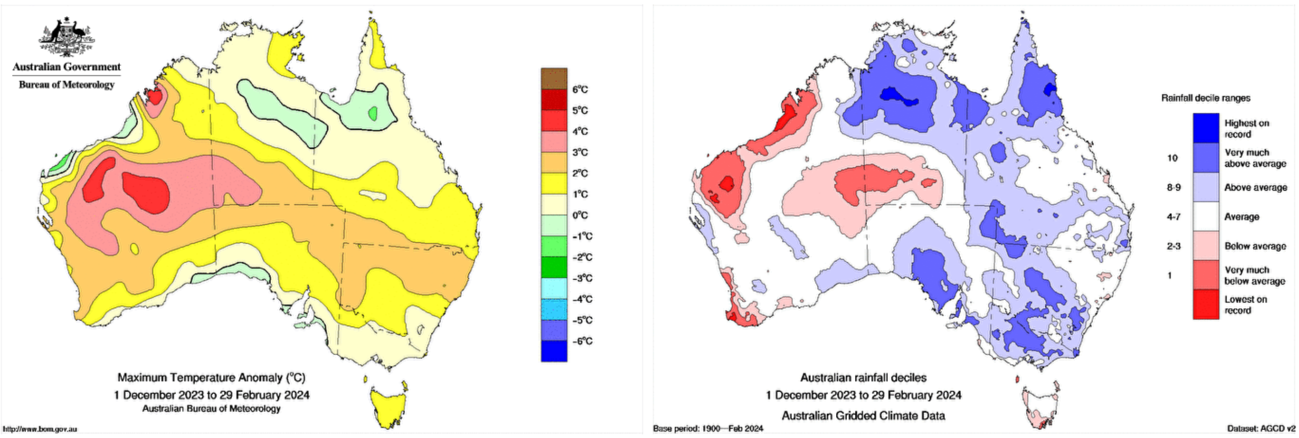
### Weather conditions in summer 2023-24

During summer 2023-24, national mean temperatures were 1.62˚C above the long-term average, with most of Australia affected by heatwaves in December and February. Daytime temperatures were above average for eastern New South Wales, and parts of north-western and far eastern Victoria while daytime temperatures were very much above average across most of Western Australia, South Australia, Tasmania, large parts of southern and far north-eastern Northern Territory, northern and western New South Wales, and Queensland[8].

Summer rainfall was 18.9% above the long-term average for Australia. Summer rainfall was above average for large parts of the eastern two-thirds of the mainland, with rainfall well above average across Queensland, New South Wales, northern parts of the Northern Territory, Victoria, and southern South Australia. Some of the major weather stations in the major NEM centres recorded their highest record of total precipitation for summer 2023-24, while below average rainfall was observed across Western Australia and Tasmania.

Maximum temperatures were either above or very well above average for the NEM regions over summer. The national mean temperature in December was 1.6°C above the long-term average, making December 2023 the fourth-warmest December on record. South Australia experienced its warmest March on record with daytime temperatures 2.86°C above the average.

**Figure 8 Mean daily maximum temperature anomaly (Left) and national rainfall deciles from 1 December 2023 to 29 February 2024**




Widespread low to severe intensity heatwaves and moisture from Tropical Cyclones over the summer period resulted in high dew points. In January, Queensland experienced maximum temperatures 1.42°C above the

[8] Australia in Summer 2023-24, Bureau of Meteorology, at http://www.bom.gov.au/clim_data/IDCKGC2AR0/202402.summary.shtml.

monthly average which resulted in record breaking demand levels, reaching a new all-time maximum operational demand record of 11,005 megawatts (MW) on Monday 22 January 2024 discussed further in Chapter 3.

While summer was warmer than average, mild temperatures (maximum temperature of 20.8°C in Melbourne OP and 26.6°C in Adelaide WT) and clear skies prevailed on New Years Eve, this combined with lower commercial load over the holiday period to drive new all-time minimum operational demand records in South Australia and Victoria. South Australia recorded -26 MW replacing the previous record of 5 MW set earlier in spring of 2023 on 1 October 2023 while Victoria recorded 1,564 MW replacing the previous record of 1,915 MW also set in spring of 2023 on 29 October 2023.

## Overall summer 2023-24 performance insights

Figure 9 and Figure 10 show the performance comparison of 2022-23 and 2023-24 summer periods across all studied weather stations and forecast horizons for Providers A, B, and C.

Key insights include:

- **Provider A** had comparable performance at all forecast horizons for all temperatures and a minor decrease in performance for the top 10% of temperatures compared to summer 2022-23**.** Provider A continued to show the lowest overall performance across all forecast horizons compared to Providers B and C.
- **Provider B** had the highest performance overall at all forecast horizons for all temperatures, and at the 1, 4, and 72 HA forecast horizons for the top 10% of temperatures. Provider B also showed significant improvements at the 1 HA horizon.
- **Provider C** had the highest performance for the top 10% of temperatures at the 24 HA forecast horizon. Provider C showed improvements in precision at the 1 HA horizon however decreased in precision at the 24 HA forecast horizon.

**Figure 9 Summer 2022-23 and 2023-24 performance comparison across major weather stations, all temperatures**

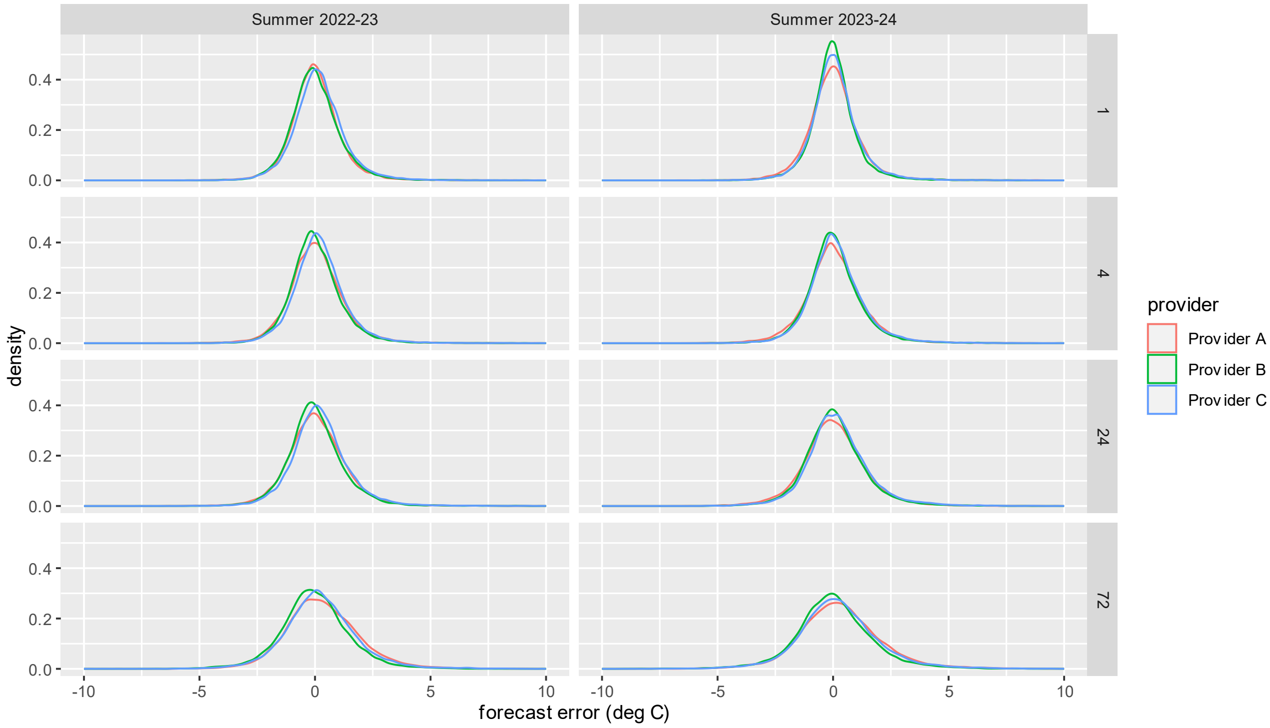
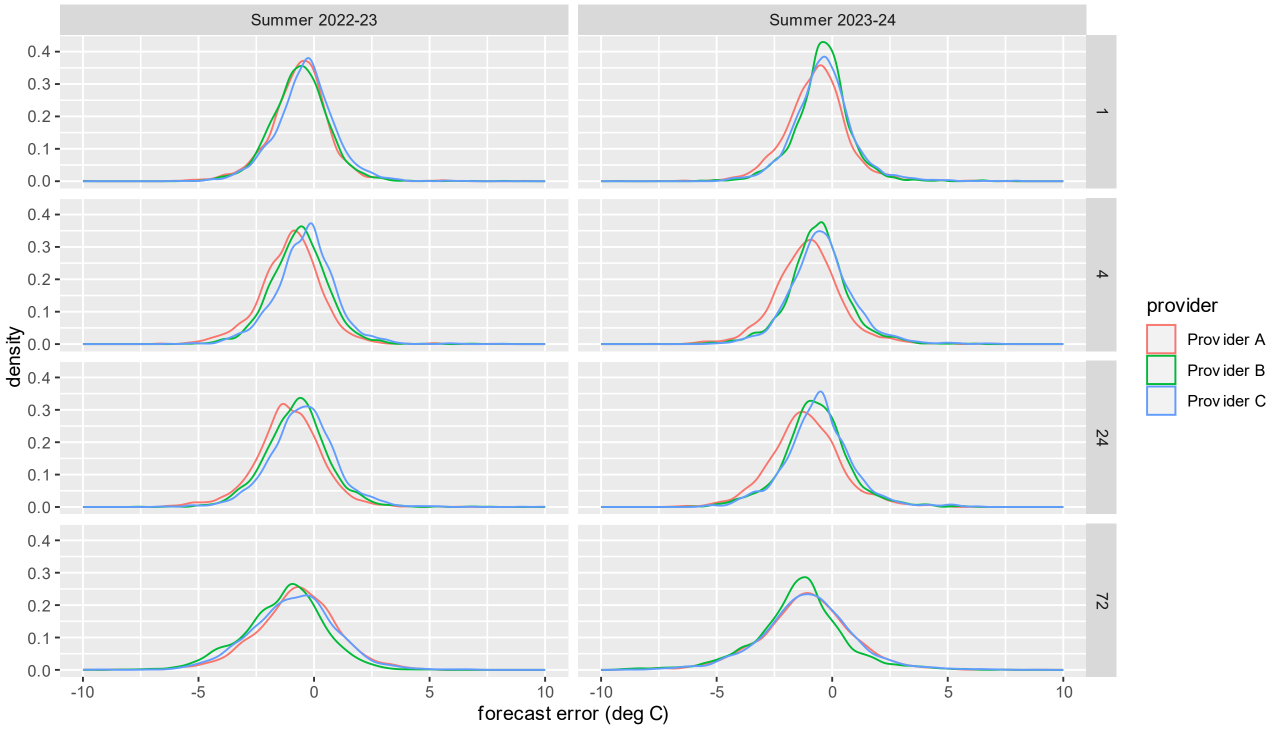


**Figure 10 Summer 2022-23 and 2023-24 performance comparison across major weather stations, top 10% of temperatures**




## 2.2 Provider A forecast performance

### Provider A had comparable performance at all forecast horizons for all temperatures compared to summer 2022-23 except the 24 HA forecast horizons.

Provider A showed an overall reduction in performance at the 24 HA forecast horizon for all temperatures compared to summer 2022-23, with a notable decrease in precision and accuracy at Adelaide WT, Hobart AP, Melbourne AP, Melbourne OP, and Penrith Lakes, seen in Figure 11. Provider A had similar performance to summer 2022-23 at the 1, 4, and 72 HA forecast horizons, but decreased performance at the 24 HA forecast horizon for all temperatures, displayed in Figure 23 (Appendix A1.2).

For the top 10% of temperatures, shown in Figure 12, Provider A exhibited an increased tendency to under-forecast (consistent with previous summer reports), but did show a major improvement in precision at Archerfield AP compared to summer 2022-23. Overall Provider A also showed a marginal decrease in accuracy and precision compared to last summer at all forecast horizons in the top 10% of temperatures, as seen in Figure 24 (Appendix A1.2).

Provider A performance was comparable to the other providers in terms of accuracy, however had the lowest performance in terms of precision, as shown in Figure 9. Provider A had the lowest overall performance out of the three weather providers over summer 2023-24 at all forecast horizons and all temperatures, and at the 1, 4, and 24 HA forecast horizons for the top 10% of temperatures (see Figure 21 and Figure 22 in Appendix A1.1).

Intraday MAE profiles in Appendix A2 show Provider A overall exhibited the highest MAE, however, generally had an improved or comparable forecast performance during the early morning at all weather stations.

**Figure 11 Major weather stations, Provider A, all summer temperatures 2022-23 and 2023-24, 24 HA**

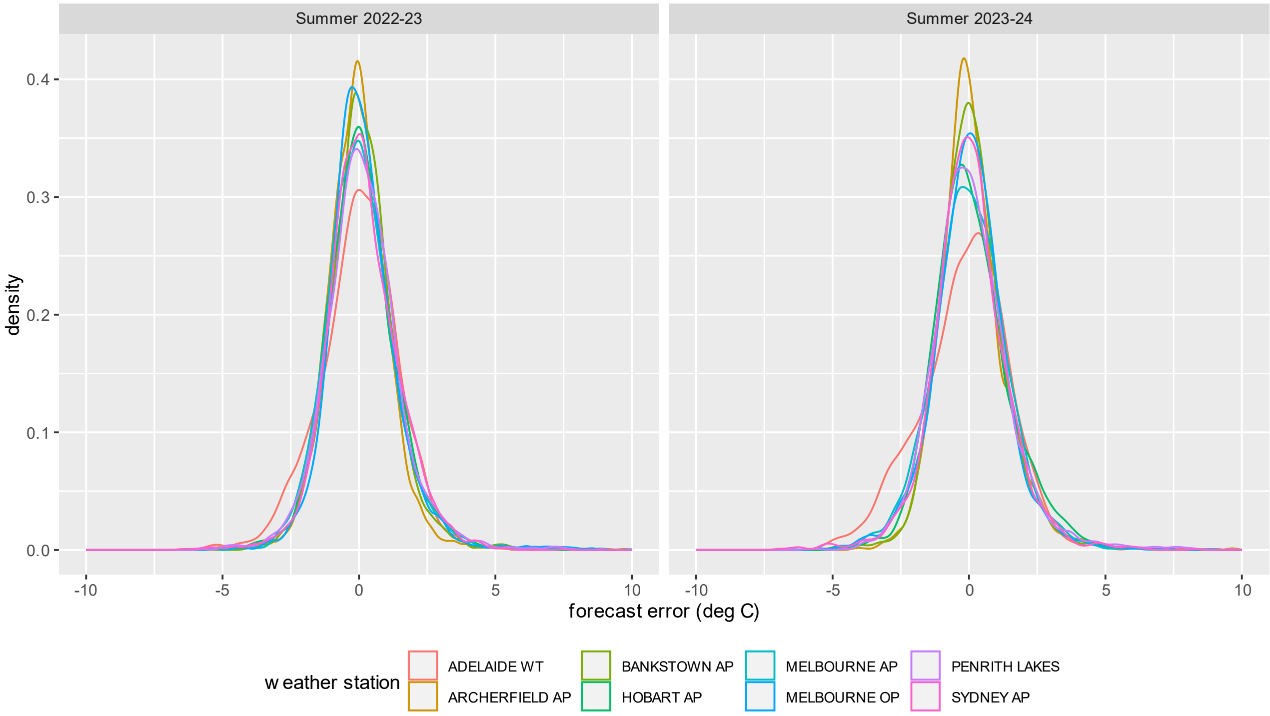
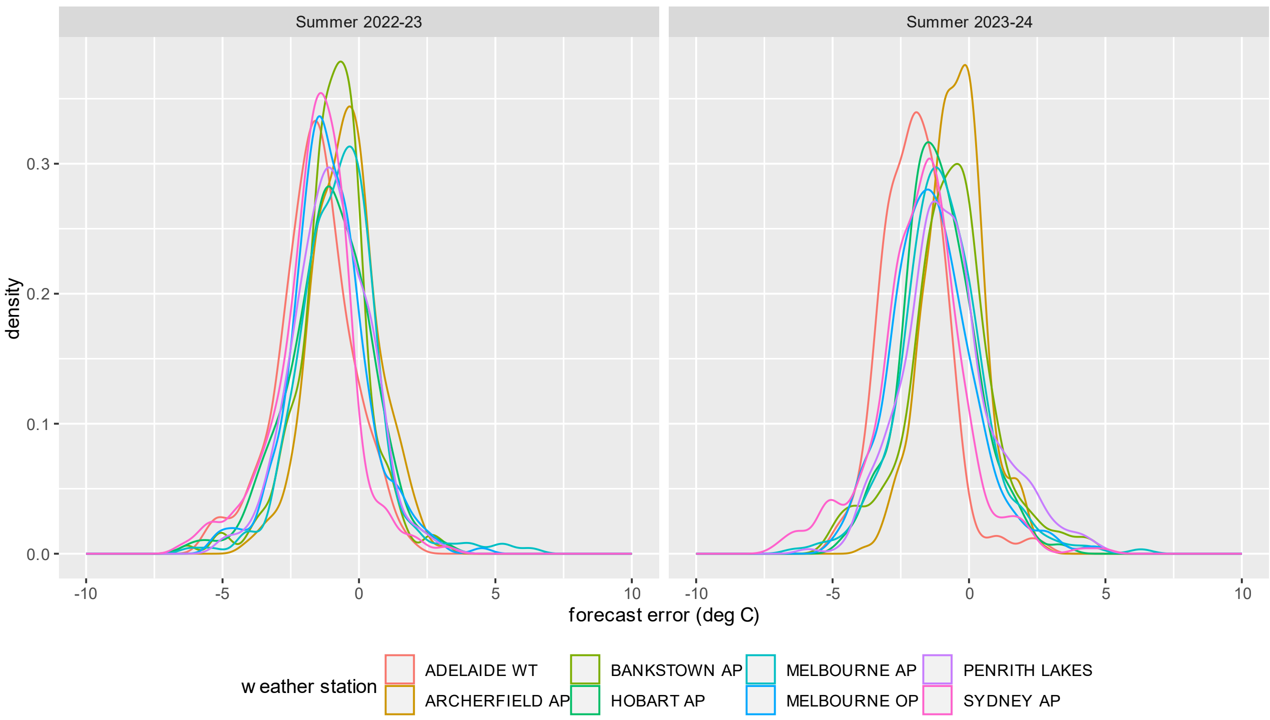



**Figure 12 Major weather stations, Provider A, top 10% summer temperatures 2022-23 and 2023-24, 24 HA**



## 2.3 Provider B forecast performance

### Overall Provider B had the highest performance of all providers, with improvements at the 1 HA forecast horizon, however decreased performance at the 24 HA forecast horizon.

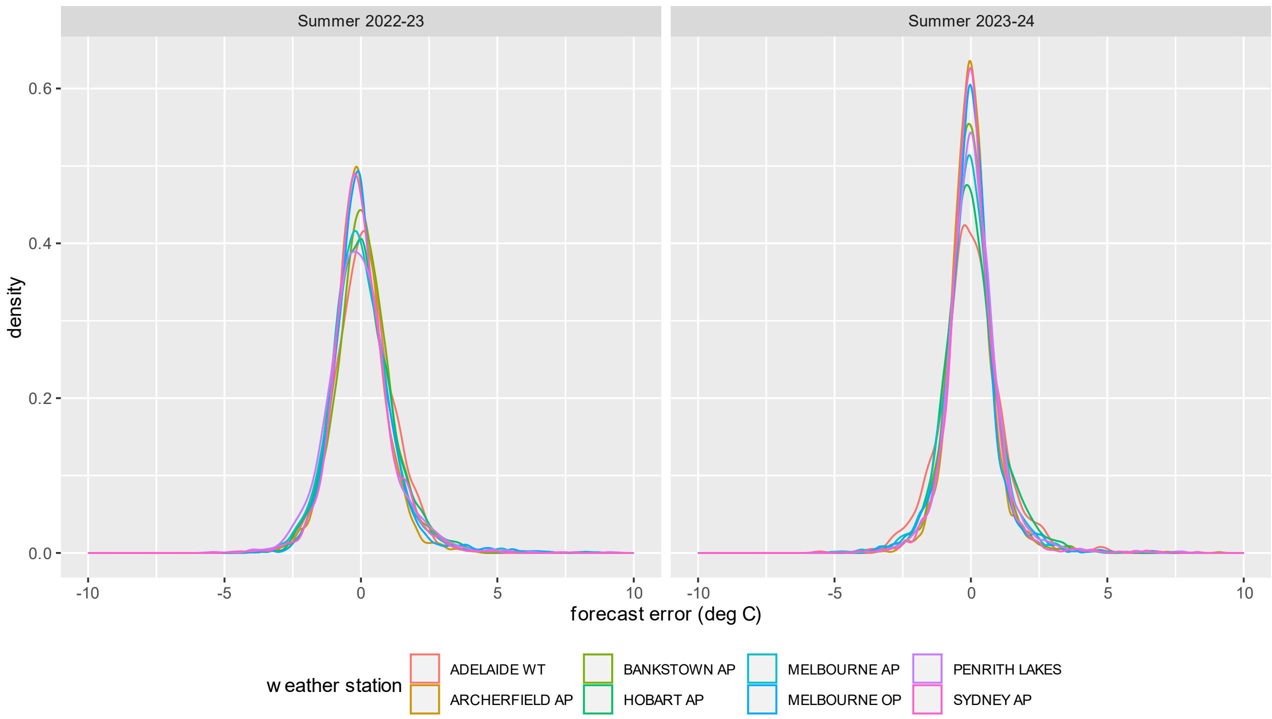
Compared to summer 2022-23, Provider B showed a marked performance increase at the 1 HA forecast horizon for both all temperatures and the top 10% of temperatures, shown in Figure 13, Figure 23 and Figure 24 (Appendix A1.2).

Provider B had the highest performance of all providers for both all temperatures and the top 10% of temperatures for all forecast horizons, with the exception of the 24 HA forecast for the top 10% of temperatures, as shown in Figure 21 and Figure 22 (Appendix A1.1).

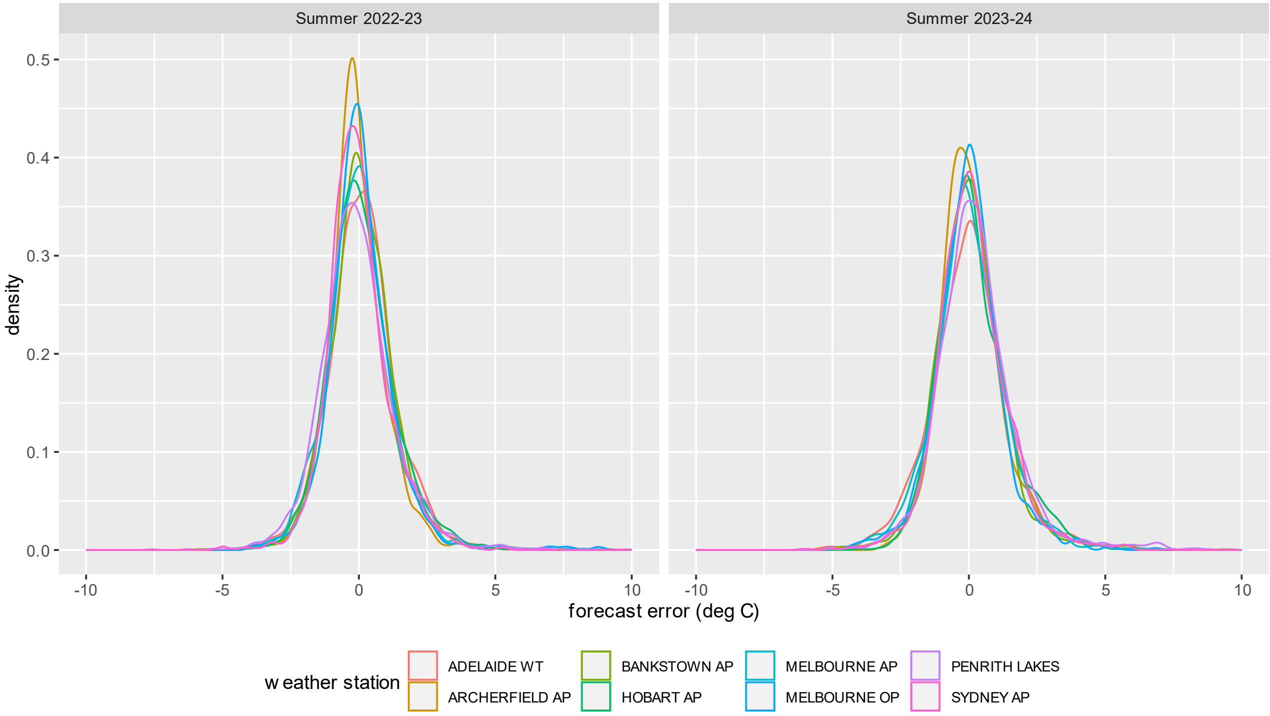
Provider B performance decreased at the 24 HA forecast horizon for all studied weather stations for all temperatures compared to summer 2022-23, with a notable decrease at Archerfield AP, shown in Figure 14. For the top 10% of temperatures, Provider B also showed an overall decrease in performance compared to summer 2022-23, most notably at Bankstown AP, however, did show an improvement at Archerfield AP, displayed in Figure 15. This shows that while Provider B had an overall reduction in performance at Archerfield AP it was more effective at higher temperatures during summer 2023-24, which assisted AEMO on extreme demand days.

As seen in summer 2022-23 and previous summer periods, and consistent with other providers, Provider B continued to show a tendency to under forecast the top 10% of temperatures at most weather stations presented in this report.

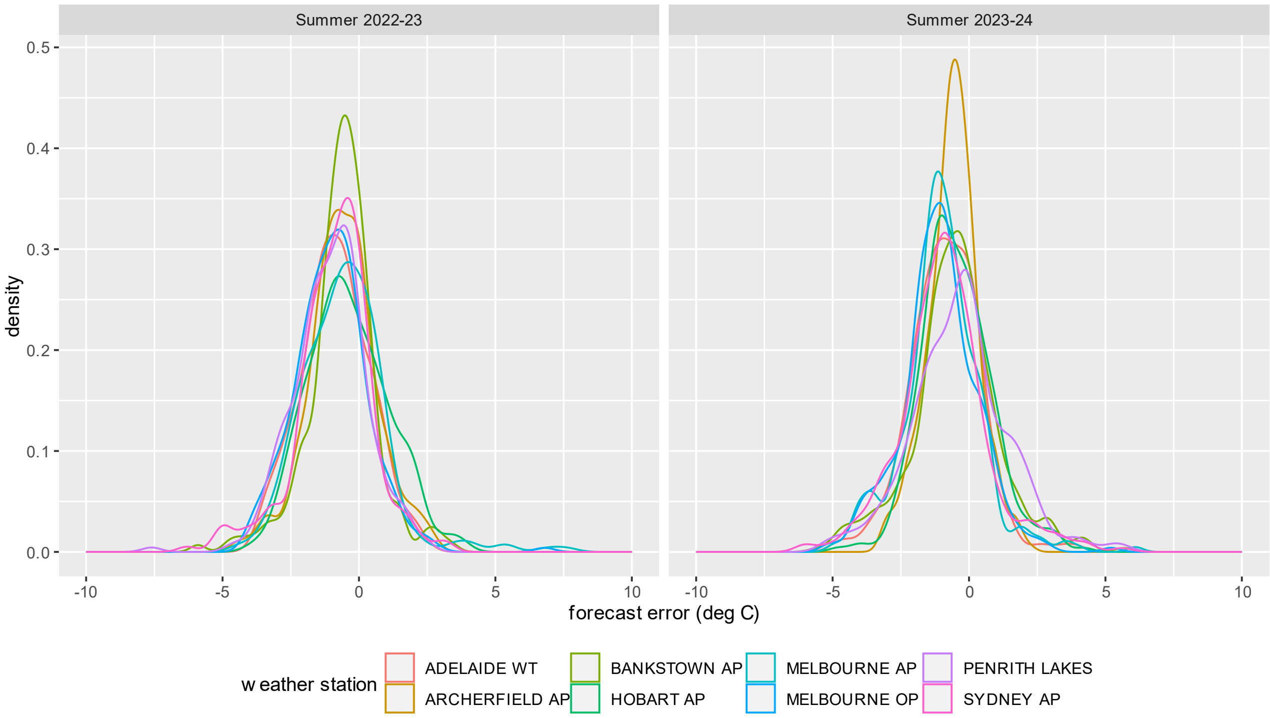
**Figure 13 Major weather stations, Provider B, all summer temperatures 2022-23 and 2023-24, 1 HA**



### Figure 14 Major weather stations, Provider B, all summer temperatures 2022-23 and 2023-24, 24 HA




### Figure 15 Major weather stations, Provider B, top 10% summer temperatures 2022-23 and 2023-24, 24 HA



## 2.4 Provider C forecast performance

### Provider C increased performance at the 1 HA forecast horizon for all temperatures and was the highest performing provider for the top 10% of temperatures at the 24 HA forecast horizon.

However, for all temperatures at the 24 HA forecast horizon, Provider C showed an overall reduction in performance compared to summer 2022-23, with a decrease in precision at Archerfield AP, Melbourne AP, Melbourne OP, and Sydney AP, as seen in Figure 16. Provider C showed improvement at the 1 HA forecast horizon compared to summer 2022-23, however performance reduced at the 24 and 72 HA forecast horizons for all temperatures, as seen in Figure 23 (Appendix A1.2). Performance at the 4 HA forecast horizon is similar to Provider B at all temperatures.

Similar to Providers A and B, Provider C had a tendency to under forecast the top 10% of temperatures at all weather stations at the 24 HA forecast horizon, as seen in Figure 17. However, Provider C demonstrated the highest accuracy and precision at these extreme temperatures compared to the other providers, shown in Figure 22 (Appendix A1.1). Provider C had a notable improvement at Archerfield AP for the top 10% of temperatures, which assisted AEMO on extreme demand days, while reductions in performance at Melbourne OP and Sydney AP were observed, shown in Figure 17.

Year-on-year performance improvements were the most notable at the 1 HA forecast horizon for Provider C, with an improvement for all temperatures and similar performance for the top 10% of temperatures compared to summer 2022-23, displayed in Figure 23 and Figure 24 (Appendix A1.2).

**Figure 16 Major weather stations, Provider C, all summer temperatures 2022-23 and 2023-24, 24 HA**

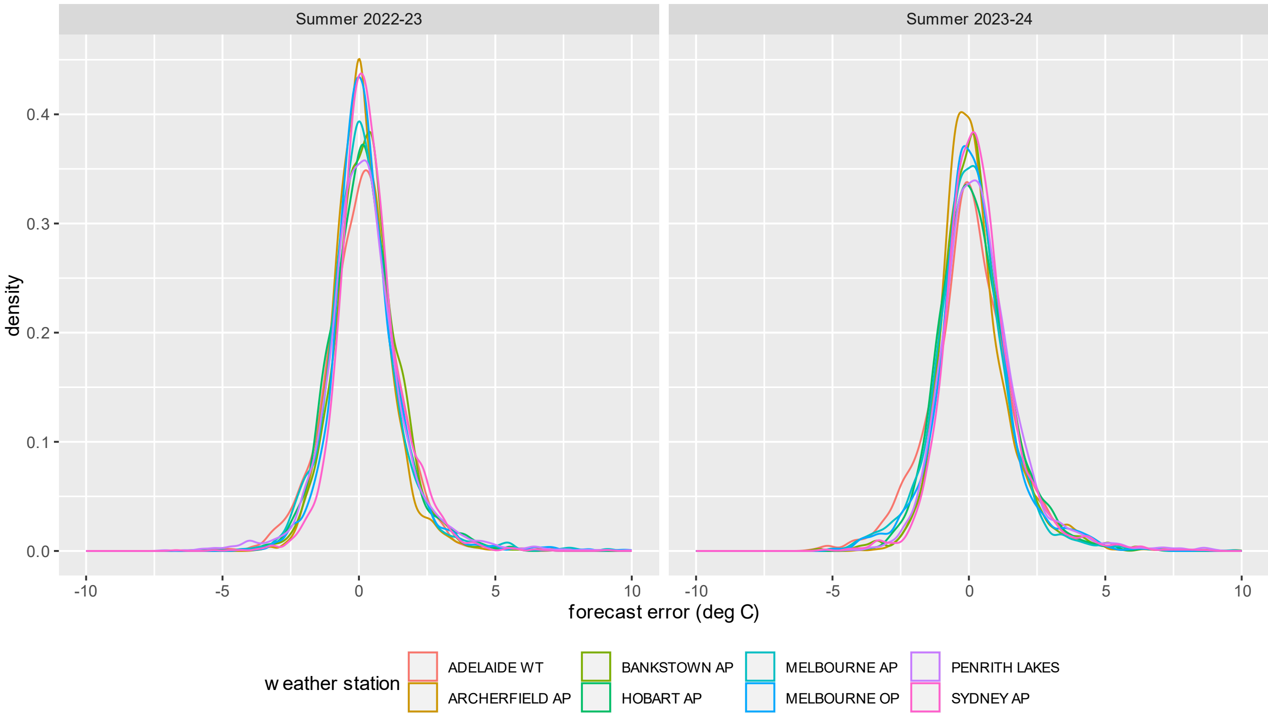
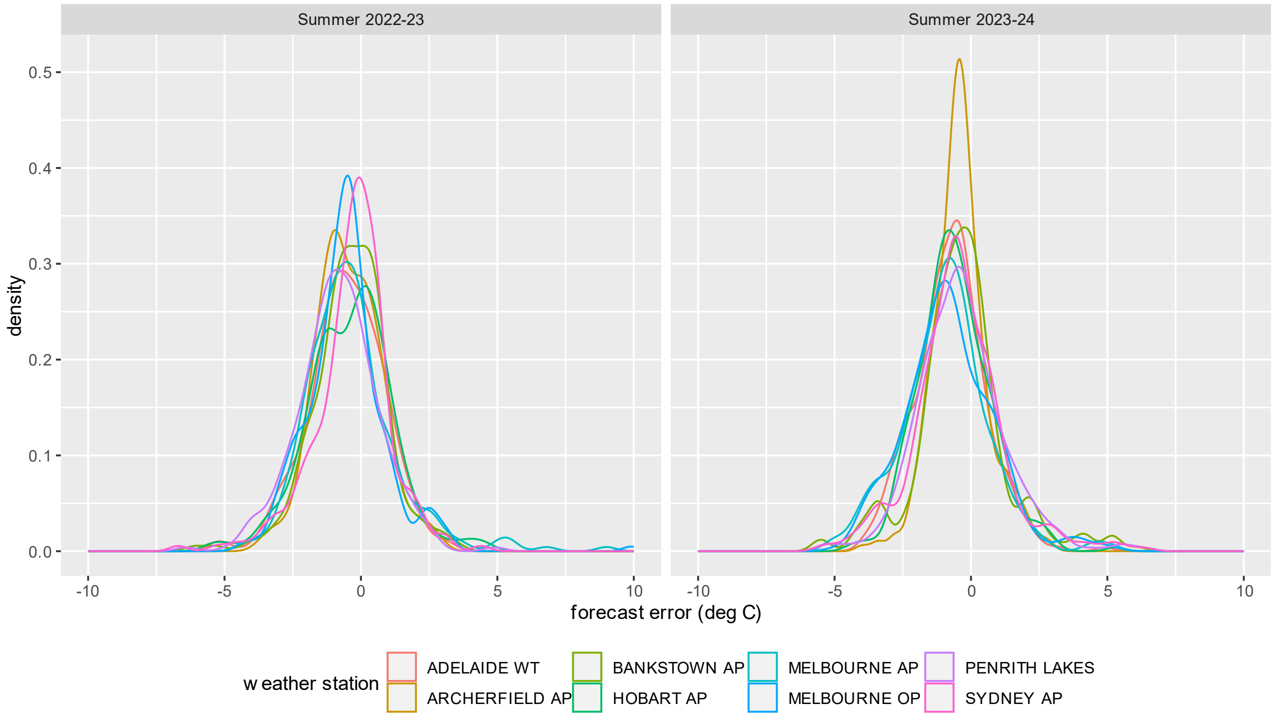


**Figure 17 Summer 2023-24 performance comparison across major weather stations, top 10% temperatures**



# 3 Case study: Persistent and widespread heat in Queensland

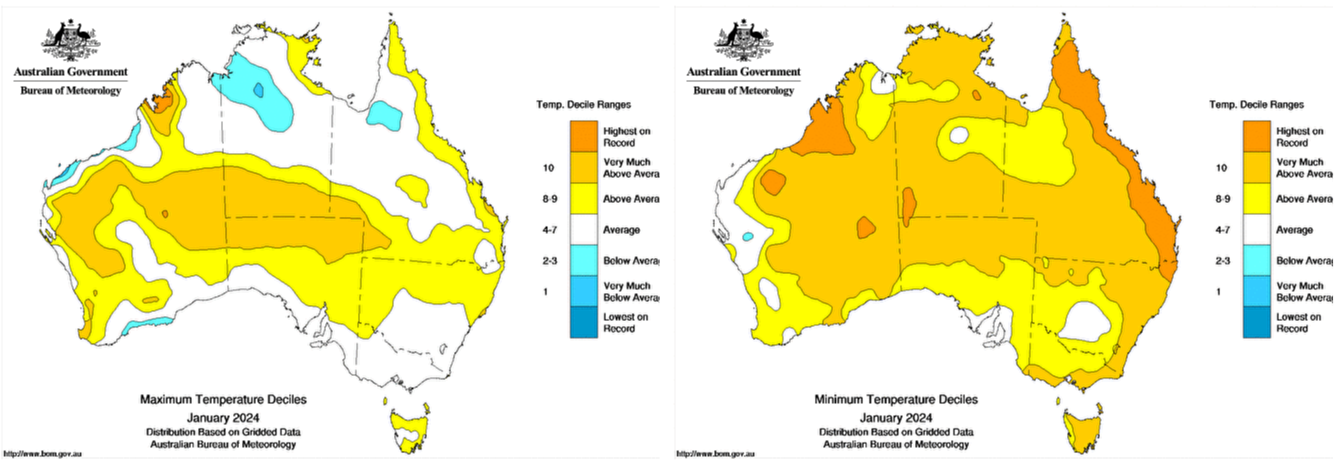
This case study explores the temperature forecasts of an extreme heat day in Southern Queensland and the subsequent impacts this had on electricity demand and rooftop PV forecasting.

In January 2024, the mean temperature across Australia was 1.54°C above the 1961-90 average and the third hottest January on record[9] (Figure 18). In addition, the mean rainfall total in January 2024 was 47.4% above the long-term average making this the ninth-wettest January on record. The abundance of moisture and hotter temperatures, especially across Queensland, resulted in elevated dew point temperatures, driving up humidity and making January 2024 the second most humid January in Queensland on record (highest since 2009).

El Niño conditions were active during November 2023 to March 2024, with hotter conditions expected for Australia after three successive La Niña cycles brought cooler conditions and above average rainfall to previous summers. El Niño events generally increase the chances of warmer and drier conditions across Australia. Figure 18 shows the increased heat conditions relative to maximum and minimum temperatures in January 2024.

The combination of heat and humidity in January 2024 resulted in east coast NEM regions experience heatwaves and record levels of daily minimum temperatures[10], driving demand to new heights in Queensland.

**Figure 18 Australian maximum and minimum temperature deciles, January 2024**




## Temperature forecasts and outcomes

On Monday 22 January 2024, heat in Queensland started to build due to a westerly airstream, while moisture from Tropical Cyclone Kirrily also advected over much of Queensland resulting in elevated humidity and high dew point temperatures. A maximum dry bulb temperature of 36.5°C at 1330 hrs was forecast at Archerfield AP day-ahead with high dew points (> 24°C) with the expectations of uncomfortably muggy conditions.

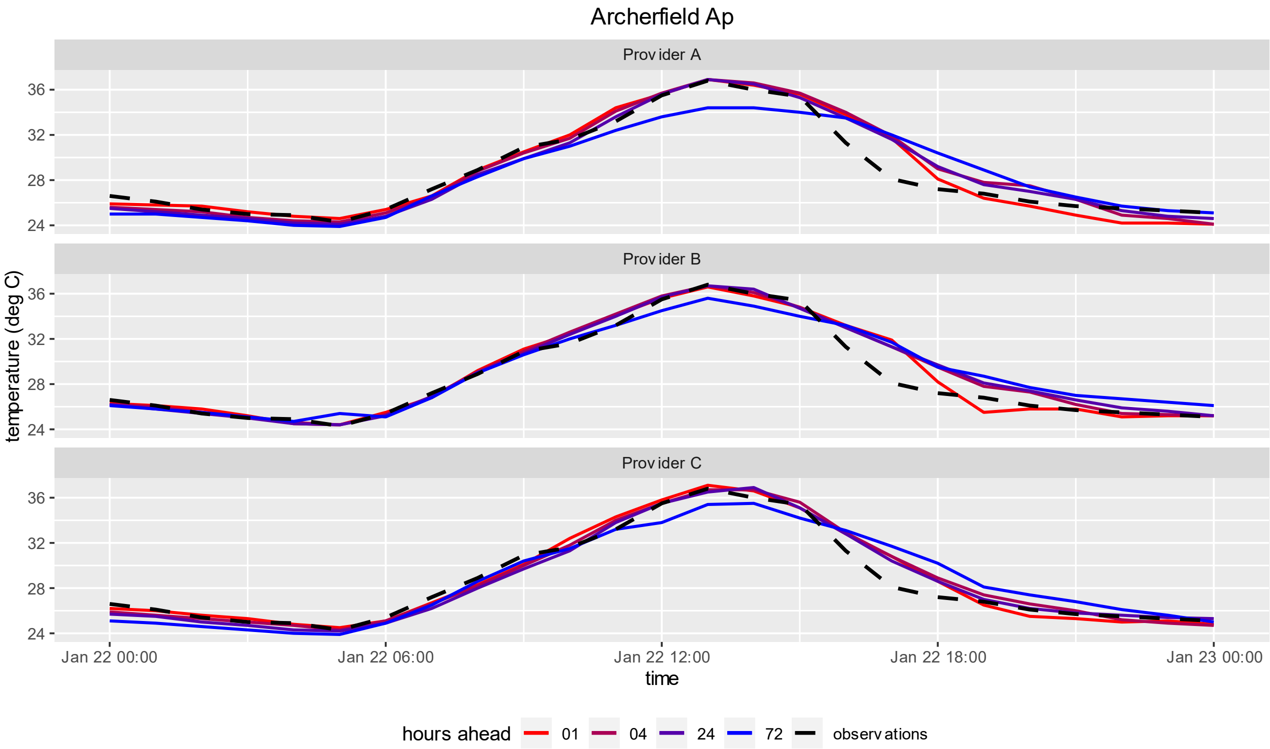
[9] See http://www.bom.gov.au/clim_data/IDCKGC2AR0/202402.summary.shtml.

[10] See http://www.bom.gov.au/clim_data/IDCKGC1AR0/202401.summary.shtml.

The actual hourly maximum dry bulb temperature at Archerfield came in higher at 36.8°C, with an accompanying dew point of 26.8°C at 1330 hrs, combining to drive extreme apparent temperatures across southeast Queensland. All weather providers at Archerfield AP had temperature forecasts close to actuals during the morning hours for all forecast horizons, as well as accurate forecasts during afternoon peak heating within 24 HA, an improvement from 72 HA where temperatures were under-forecast during the middle of the day.

Temperatures in the afternoon, particularly between 1600 and 1800 hrs were over-forecast by all providers across all forecast horizons by up to 3°C due to an earlier than expected cool change and storm development, with associated cloud development having an impact of rooftop PV generation and in turn operational demand.

**Figure 19 Forecast temperatures at various horizons against actual temperature observations for each provider at Archerfield AP on 22 January 2024**



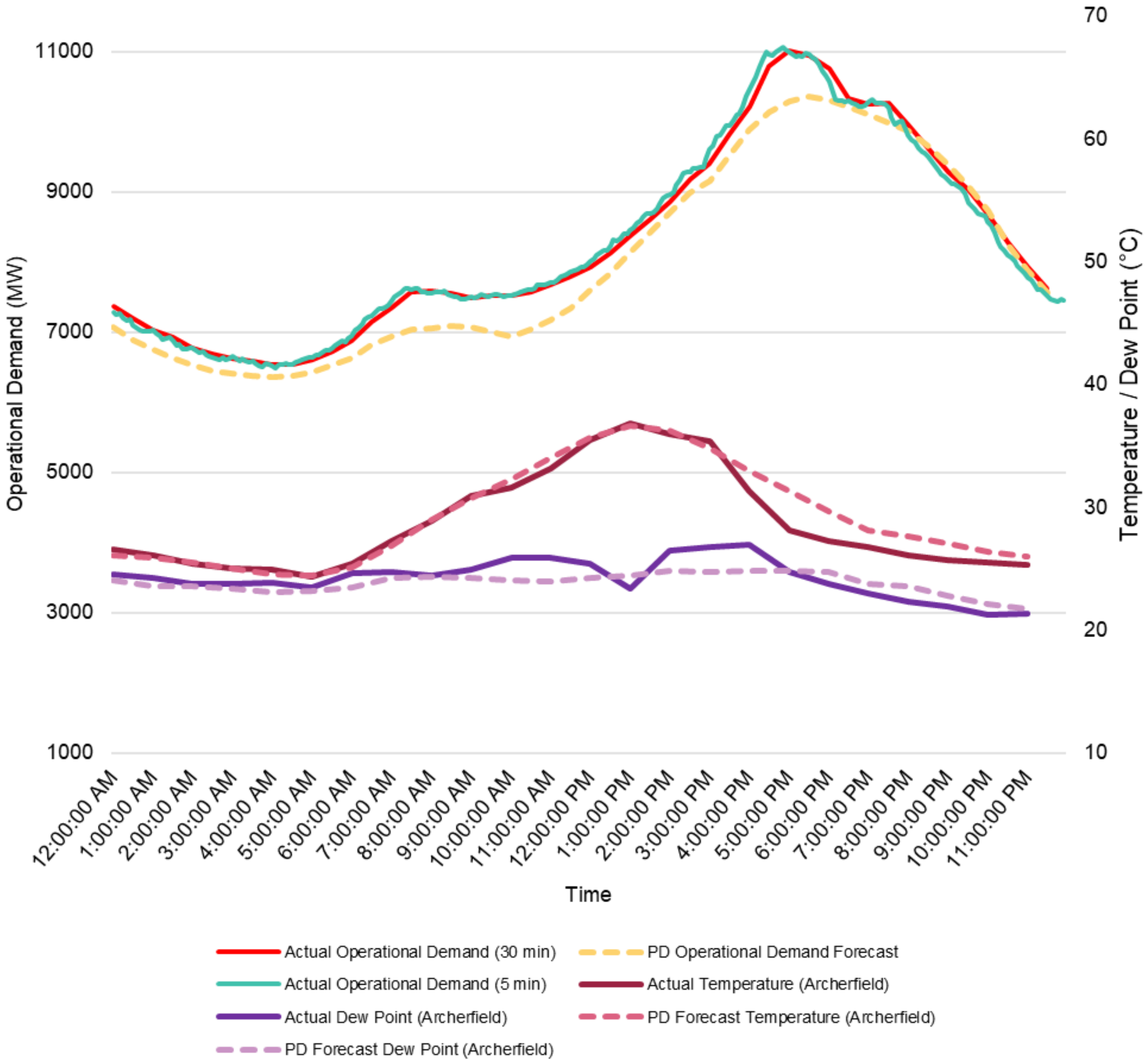

## Demand forecasts and outcomes

Due to the extreme conditions, Queensland recorded a maximum operational demand record of 11,005 MW at 1700 hrs. This surpassed the previous record of 10,070 MW by 935 MW, set on Friday 17 March 2023, and was the first-time operational demand had exceeded 11,000 MW. In addition to extreme conditions, the underlying load growth in Queensland discussed in Section 1.2 is also considered a factor for peak demand days, including this one, due to the increase in load responsiveness at high temperatures. Operational demand in Queensland also exceeded the previous demand record on Tuesday 6 February 2024 (10,242 MW) and Saturday 27 January 2024 (10,150 MW), the latter the highest Queensland demand recorded on a weekend. These high demand days share similarities in elevated dry bulb temperature and extreme dew point temperatures.

Monday 22 January 2024 shared similarities with the previous record day (17 March 2023) in terms of lead-in and on-day conditions, with temperatures on 22 January approximately 2°C higher and marginally higher levels of humidity. The day-ahead forecast was approximately 700 MW higher than the previous record due to high forecast temperatures, humidity, and latent load growth. At the day ahead horizon, an adjustment was made to decrease the evening peak forecast by up to 500 MW to a level that was deemed reasonable when assessing against previous demand records, prevailing weather conditions, and considering load growth factors.

Figure 20 shows the deviation between the actual operational demand recorded and the day-ahead Pre-Dispatch (PD) forecast, fixed at 1230 hrs the previous day, for Queensland on Monday 22 January 2024. As discussed previously, temperatures were tracking well against forecast until the late afternoon, and dew point temperature remaining elevated above 20°C throughout the day, observed around 2°C higher than forecast day-ahead. The sustained high temperature and high dew points led to an increased cooling load and decreased air conditioner efficiency, resulting in the actual demand tracking higher than the day-ahead forecast throughout the day.

**Figure 20 Operational demand, pre-dispatch forecast, temperature, and humidity in Queensland on Monday 22 January 2024**



In addition, during the afternoon, cloud cover brought by a trough moved through the metropolitan area which significantly reduced rooftop PV generation and in turn rapidly increased demand above the day-ahead forecast, leading to an earlier than forecast evening peak of 11,005 MW. During this rooftop PV reduction against the evening peak, known as a “solar squeeze”, demand increased by 800 MW between 1500 hrs and 1600 hrs, which created challenges in managing the operational forecast leading up to and during peak intervals.

# 4 Conclusions

The results and insights presented in this report supplement the findings of previous *Temperature Forecast Analysis* reports and will continue to aid operational forecasting and decision-making at AEMO. This report is to be shared with current and potential weather service providers to draw attention to areas of improvement and help assist in baselining performance. AEMO is continuing to work with the weather forecasting industry on developing weather forecast products tailored for the energy industry as well as addressing the key challenges identified in this report.

The key findings of this report are:

- **Provider A** had comparable performance at all forecast horizons for all temperatures and a minor decrease in performance for the top 10% of temperatures compared to summer 2022-23. Provider A continued to show the lowest overall performance across all forecast horizons compared to Providers B and C.
- **Provider B** had the highest performance overall at all forecast horizons for all temperatures, and at the 1, 4, and 72 HA forecast horizons for the top 10% of temperatures. Provider B also showed significant improvements at the 1 HA horizon.
- **Provider C** had the highest performance for the top 10% of temperatures at the 24 HA forecast horizon**.** Provider C showed improvements in precision at the 1 HA horizon however decreased in precision at the 24 HA forecast horizon.
- **All providers** showed a tendency to under forecast the top 10% of temperatures at most of the weather stations. The top 10% of forecast temperatures at Archerfield AP showed improvements from all providers compared to summer 2022-23.

In 2024, AEMO is continuing to work with the weather forecasting industry to ensure weather forecast tools are developed for the purposes of energy forecasting. Initiatives include:

- Redevelopment of AEMO's Projected Assessment of System Adequacy (PASA) to be probabilistic and include weather uncertainty margins in reserve calculations.
- Establishment of new weather observation stations located with renewable energy zones (REZs) near remote variable renewable energy (VRE) generators and in metropolitan heat islands to support weather forecasting.
- Accessing a range of probabilistic weather forecasts from providers to improve situational awareness and better represent extreme weather risk and operational envelopes in demand forecasts.
- AEMO's NEM Local Temperature Alerts process, recently updated in October 2023[11], and updates to AEMO's abnormal conditions reclassification criteria[12] to include actions for severe weather phenomena.
- Considering a fourth provider which utilises AI-powered models with higher spatial and temporal resolution than conventional models to forecast wind speed, irradiance, and temperature for energy forecasts.

[11] NEM Local Temperature Alerts process: https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/projected-assessment-of-system-adequacy/nem-local-temperature-alerts#:~:text=When%20forecast%20temperatures%20for%20these,in%20their%20dispatch%20offers%20or.

[12] See section 8 in AEMO's Power System Security Guidelines: https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/power_system_ops/procedures/so_op_3715-power-system-security-guidelines.pdf?la=en

The next *Temperature Forecast Analysis* report, focusing on winter 2024, is to be published next year.

# A1. Error density plots

## A1.1 2023-24 summer performance

**Figure 21 Summer 2023-24 performance comparison across all weather stations, all temperatures**

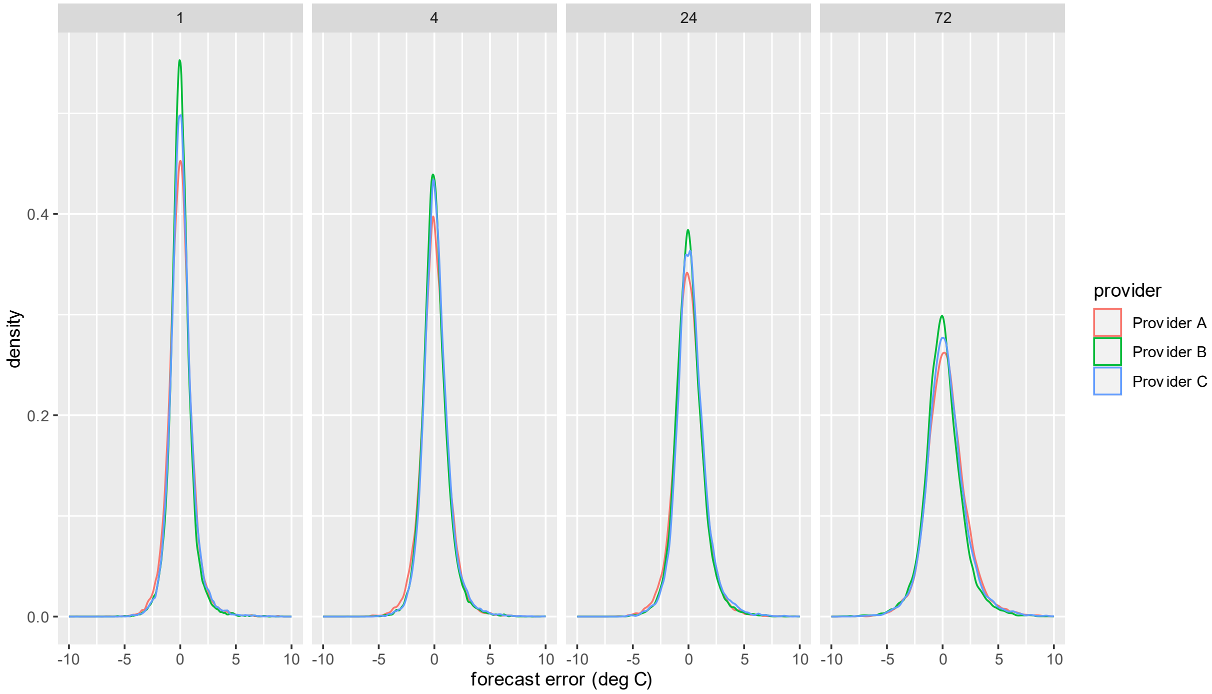
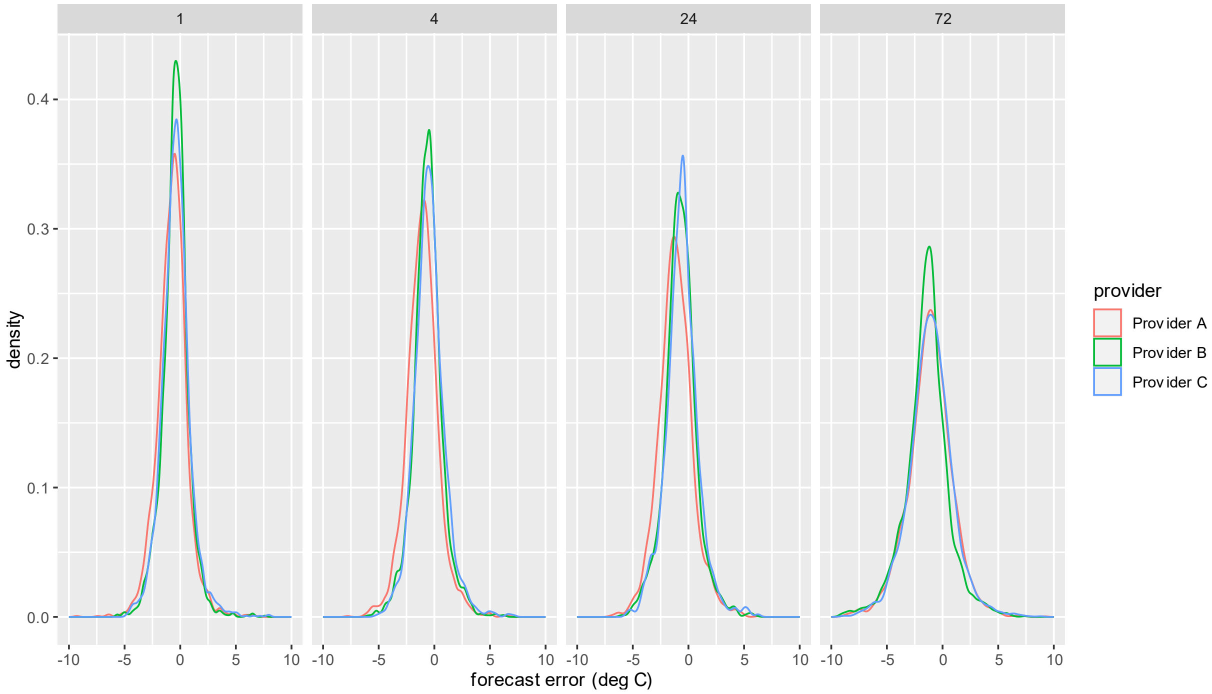



**Figure 22 Summer 2023-24 performance comparison across all weather stations, top 10% of temperatures**



## A1.2 Summer performance comparison across all weather stations

**Figure 23 Summer performance comparison across all weather stations (2022-23 and 2023-24), all temperatures**

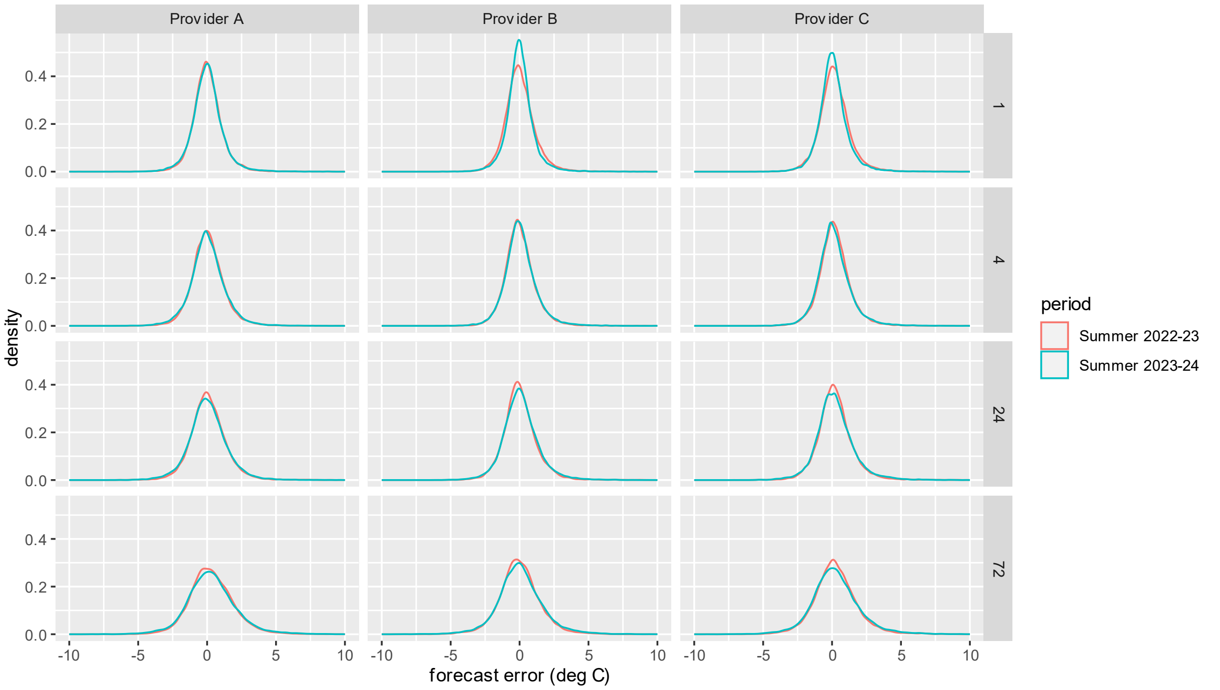
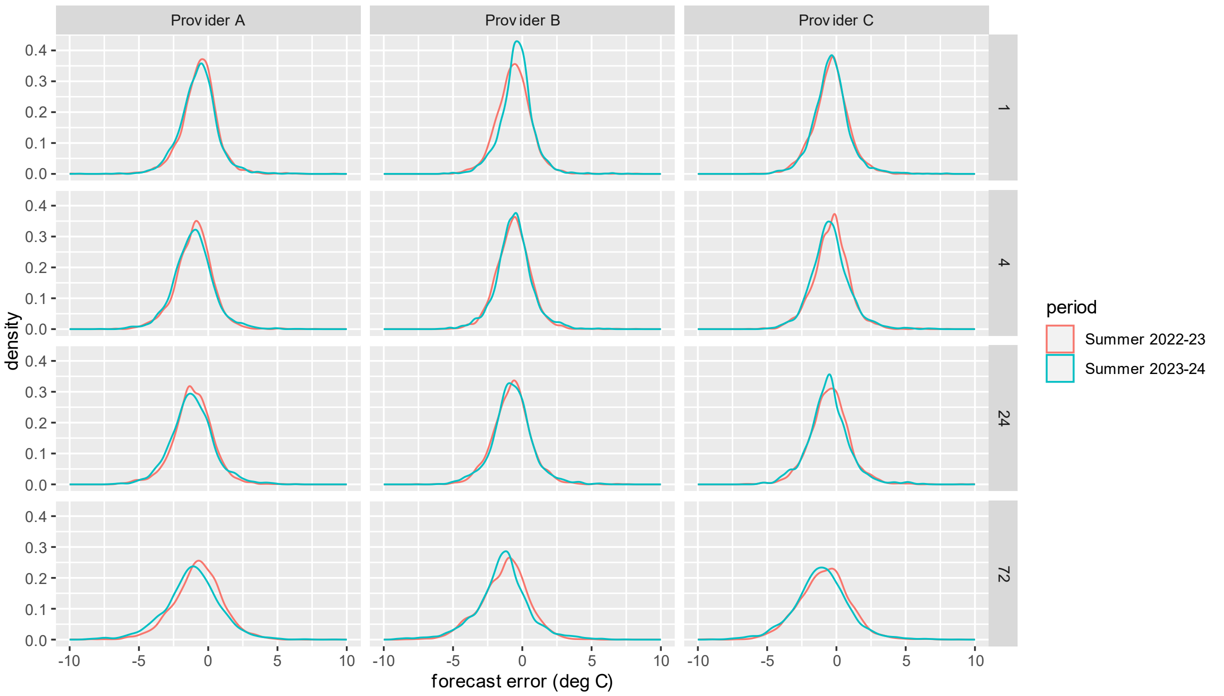



**Figure 24 Summer performance comparison across all weather stations (2022-23 and 2023-24), top 10% temperatures**



## A1.3 Station comparison by provider

**Figure 25 Major weather stations, Provider A, all summer temperatures 2022-23 and 2023-24, 24 HA**

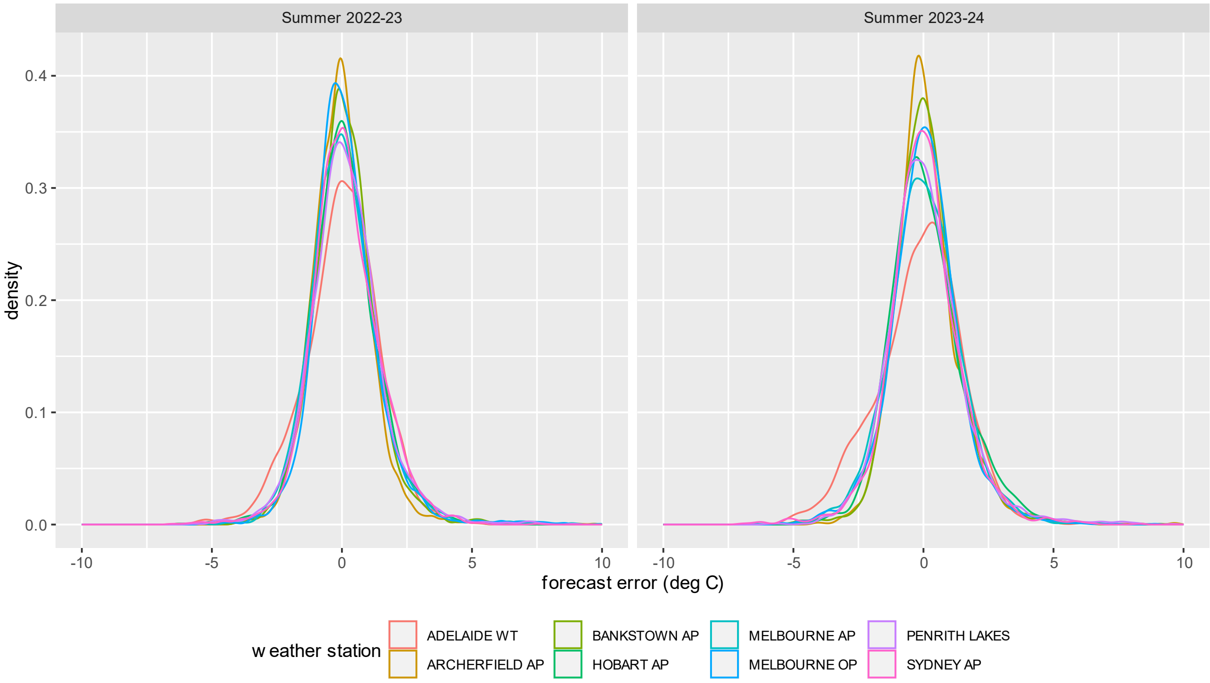



**Figure 26 Major weather stations, Provider A, top 10% summer temperatures 2022-23 and 2023-24, 24 HA**

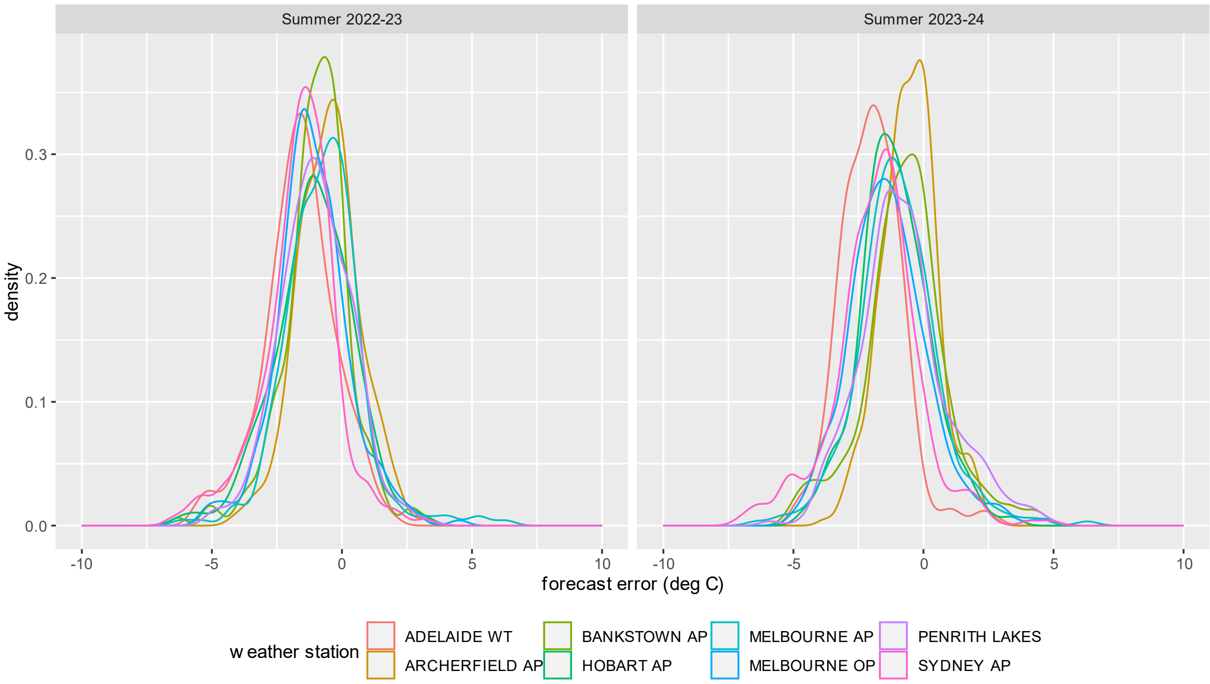


**Figure 27 Major weather stations, Provider B, all summer temperatures 2022-23 and 2023-24, 24 HA**

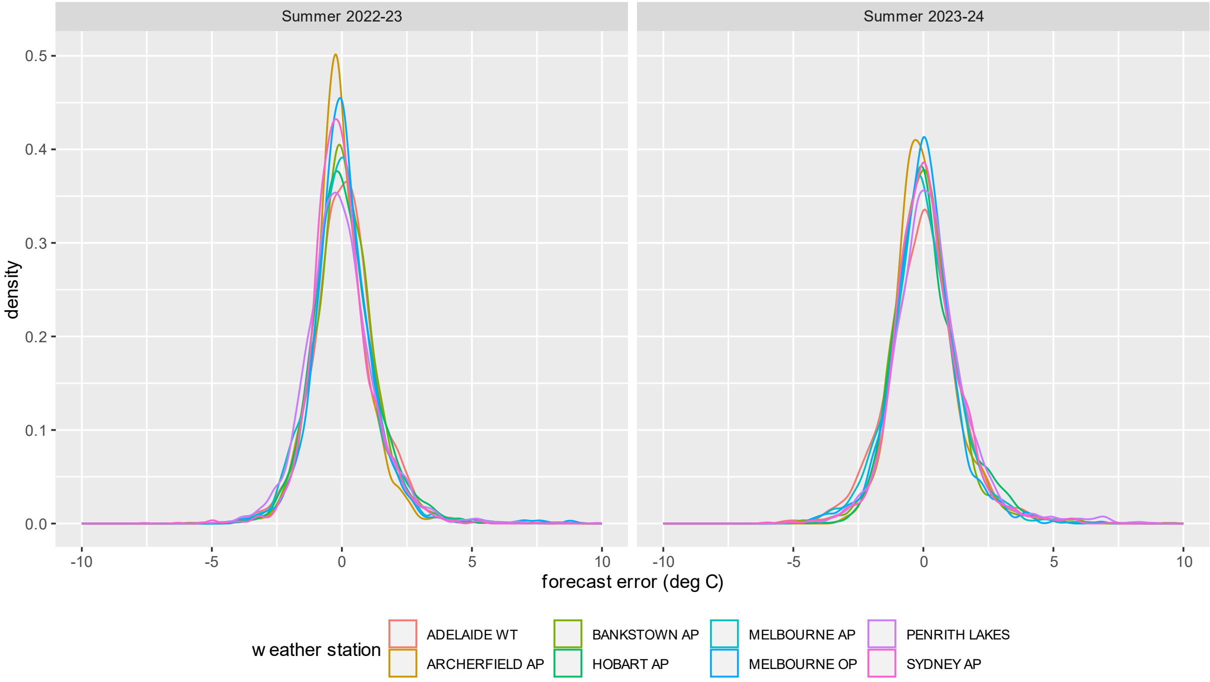



**Figure 28 Major weather stations, Provider B, top 10% summer temperatures 2022-23 and 2023-24, 24 HA**

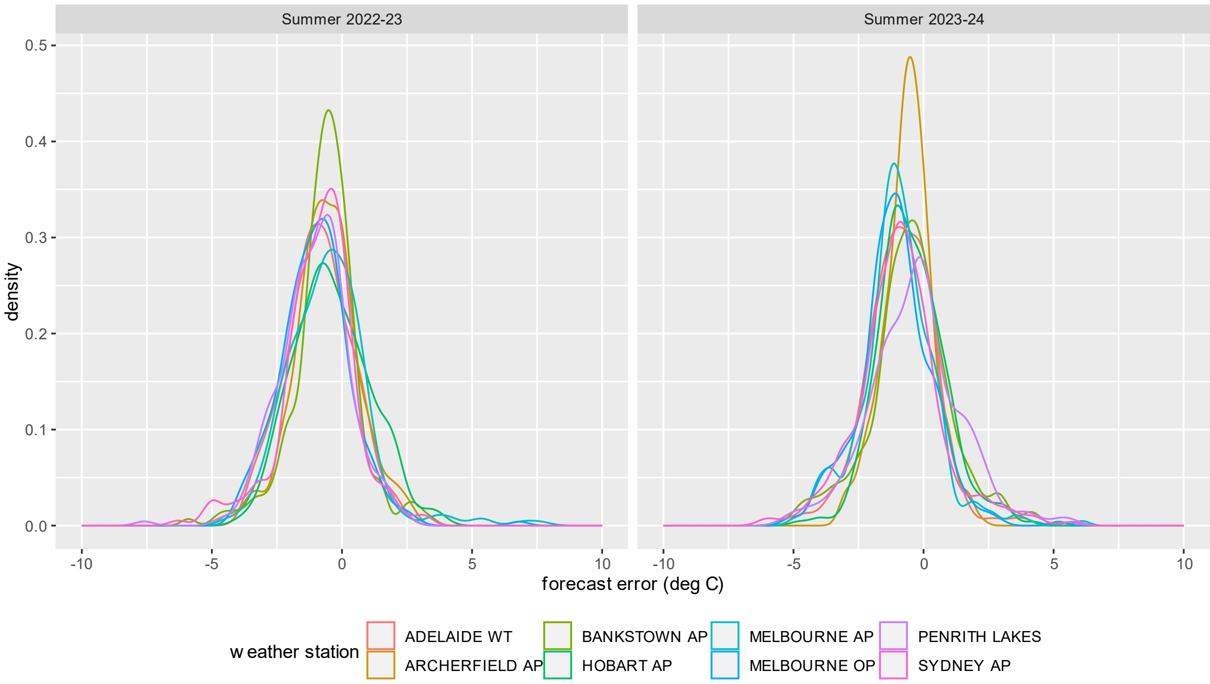


**Figure 29 Major weather stations, Provider C, all summer temperatures 2022-23 and 2023-24, 24 HA**

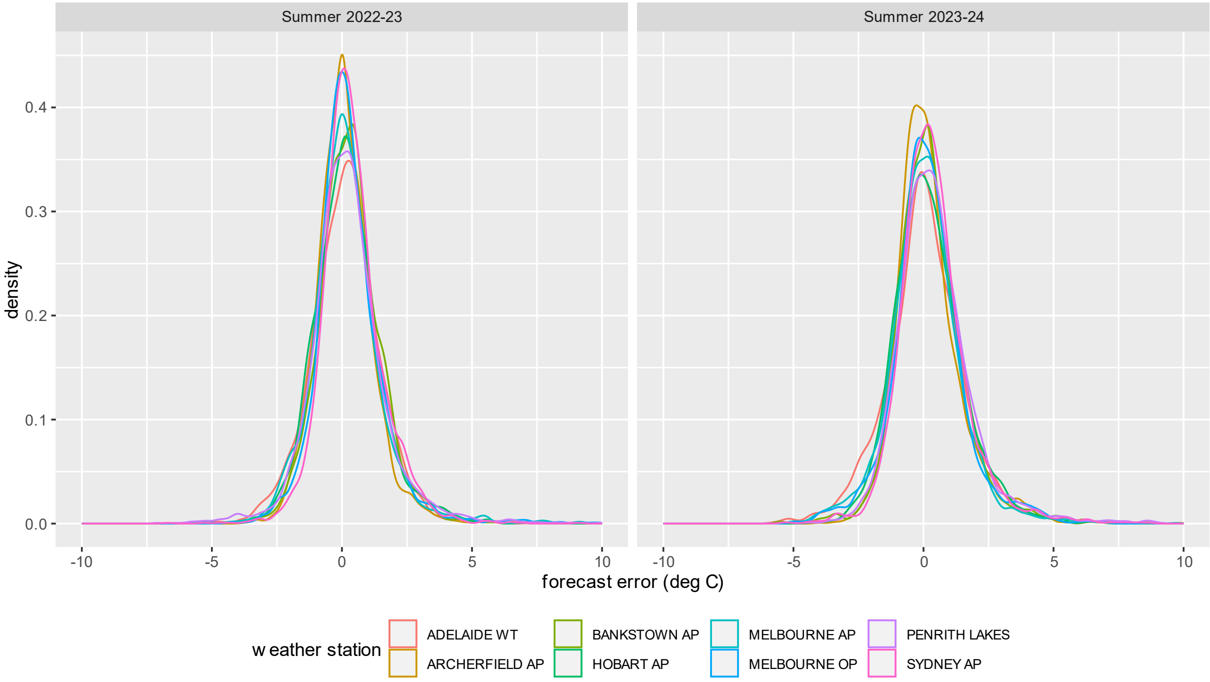
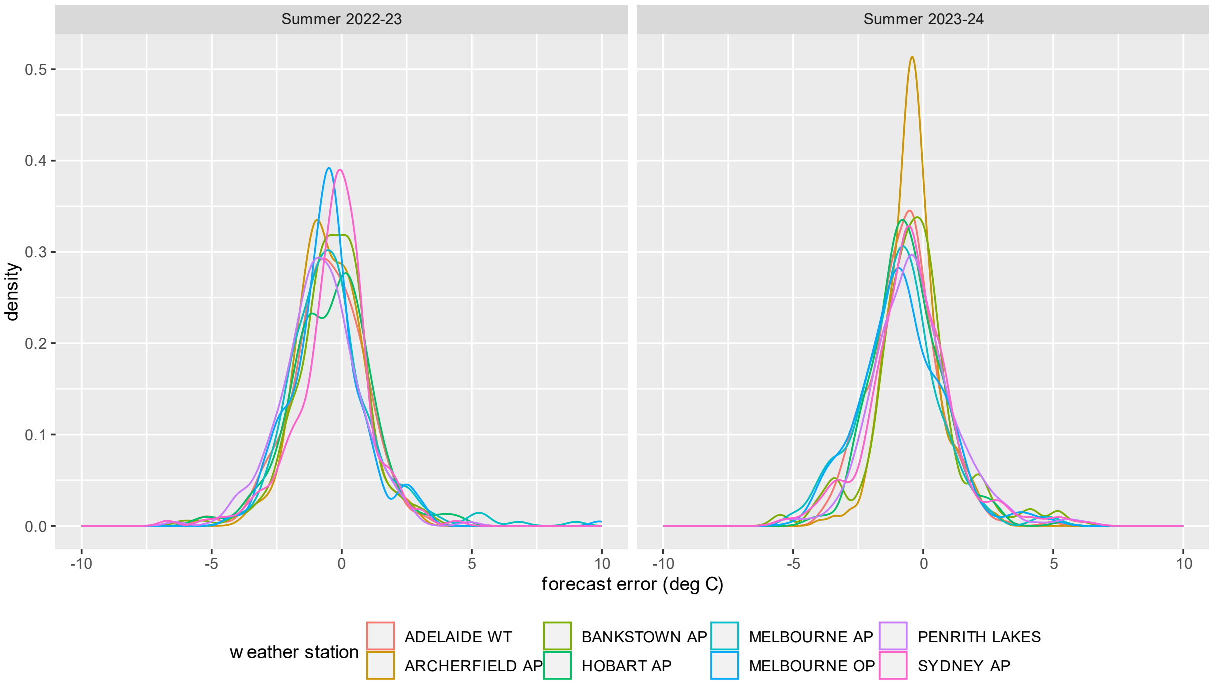
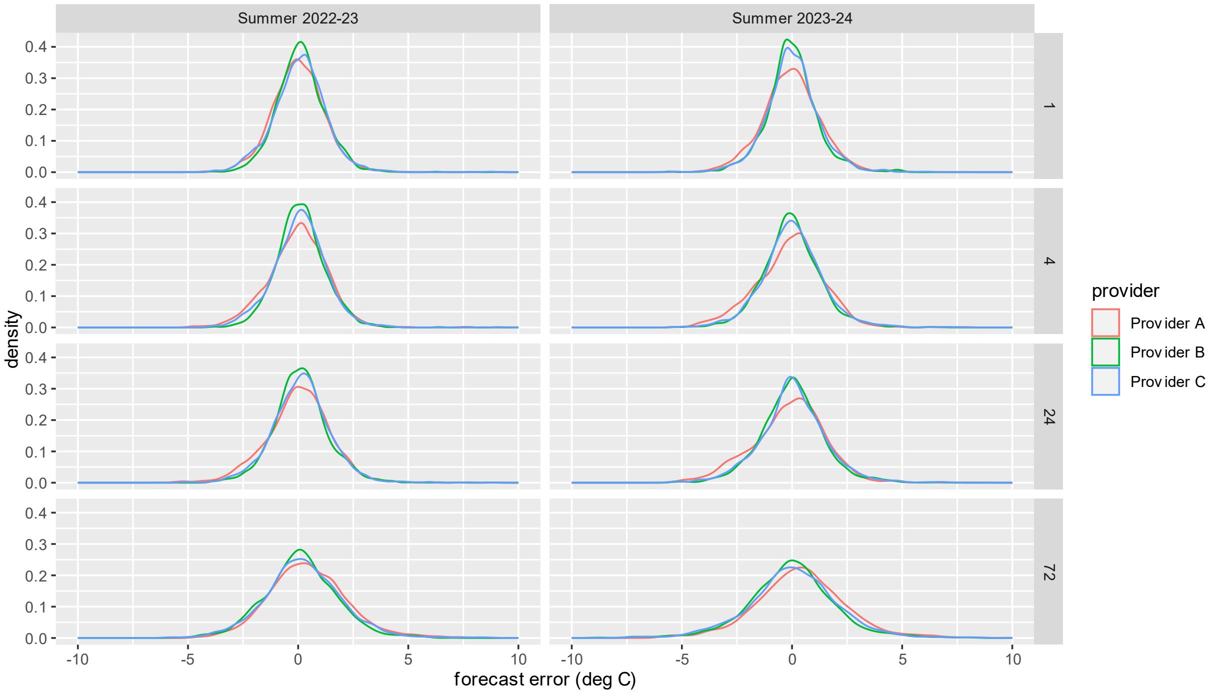



**Figure 30 Major weather stations, Provider C, top 10% summer temperatures 2022-23 and 2023-24, 24 HA**



## A1.4 Provider comparison by weather station

### Figure 31 Adelaide WT, all summer temperatures 2022-23 and 2023-24, all time horizons




### Figure 32 Archerfield AP, all summer temperatures 2022-23 and 2023-24, all time horizons

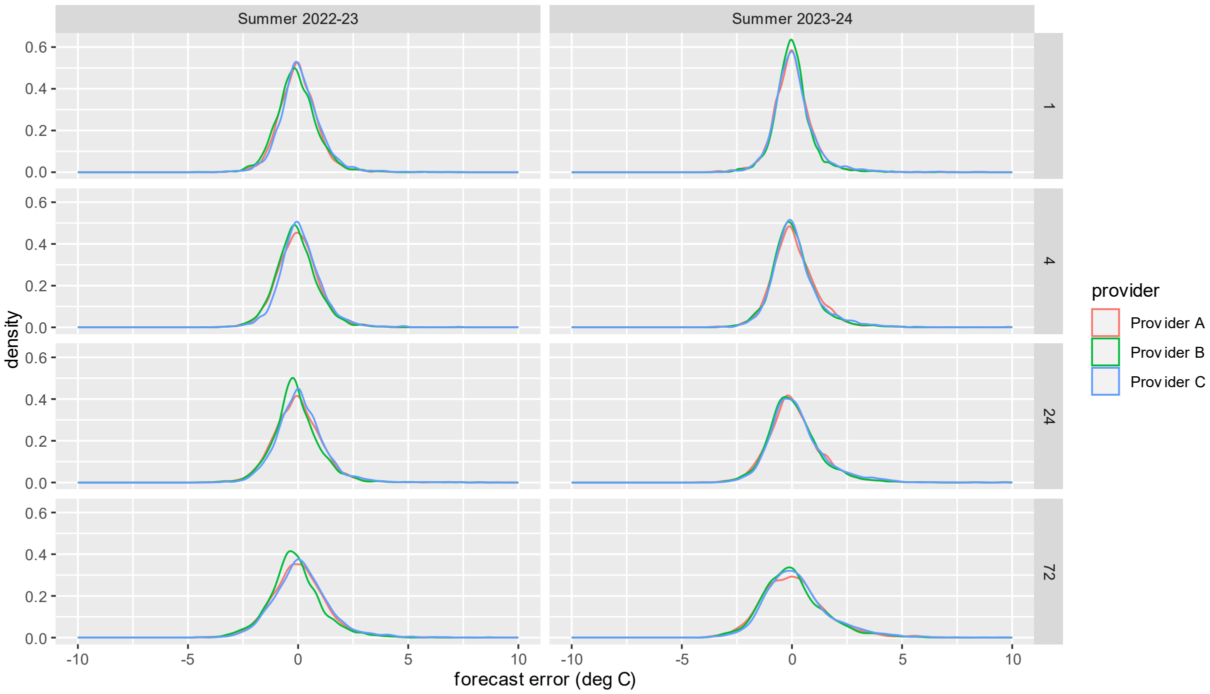


**Figure 33 Bankstown AP, all summer temperatures 2022-23 and 2023-24, all time horizons**

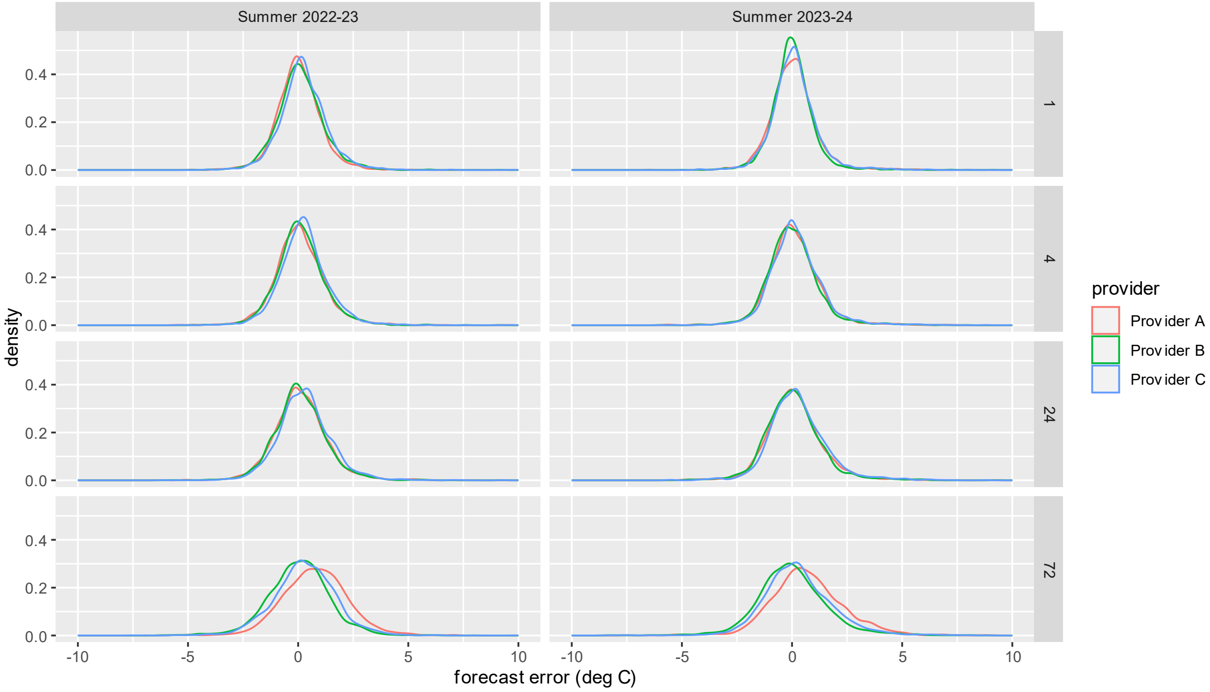



**Figure 34 Hobart AP, all summer temperatures 2022-23 and 2023-24, all time horizons**

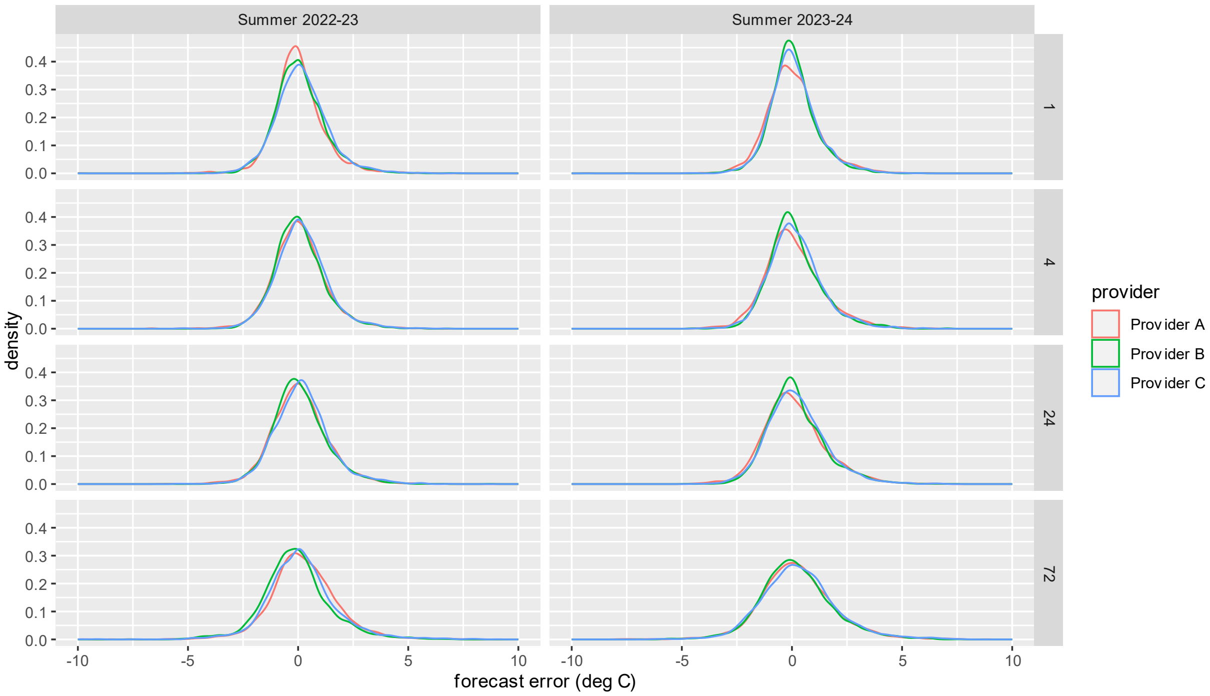


**Figure 35 Melbourne AP, all summer temperatures 2022-23 and 2023-24, all time horizons**

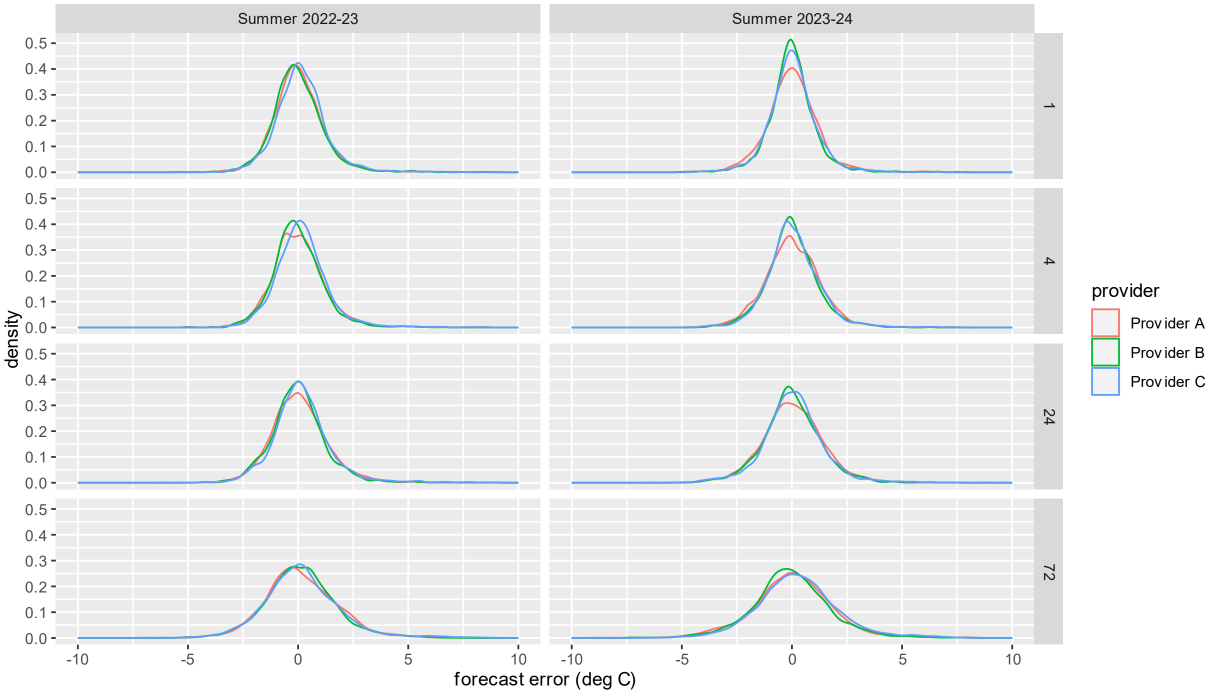



**Figure 36 Melbourne OP, all summer temperatures 2022-23 and 2023-24, all time horizons**

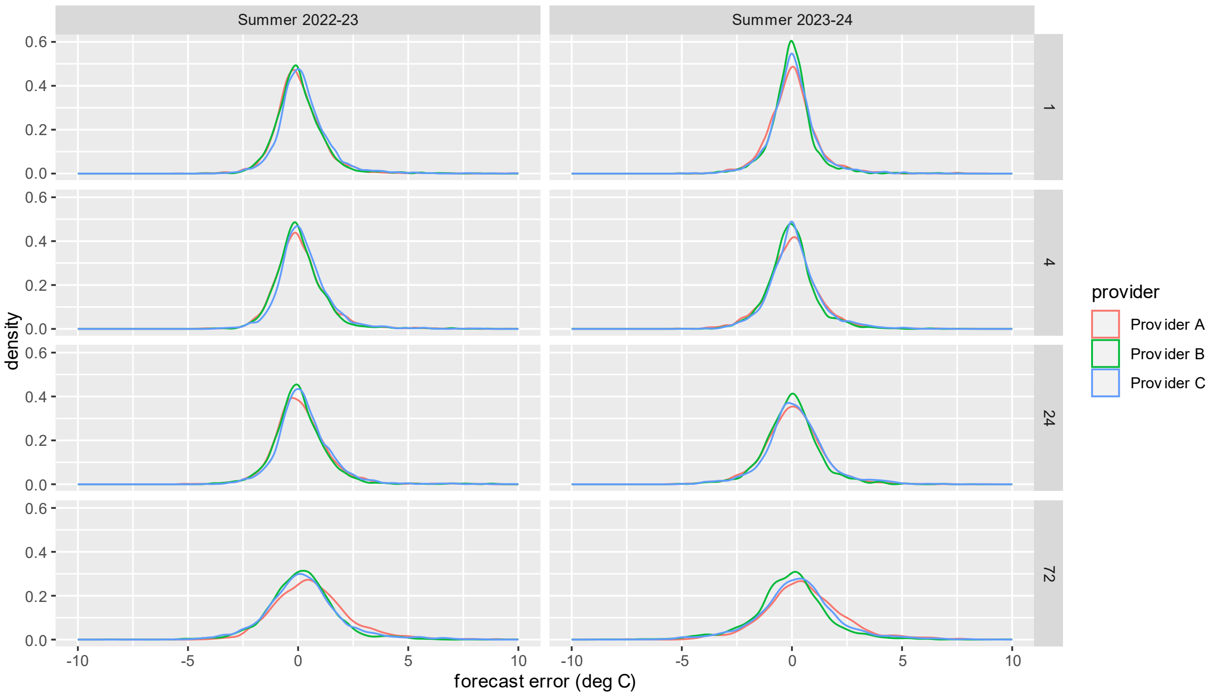


**Figure 37 Penrith Lakes, all summer temperatures 2022-23 and 2023-24, all time horizons**

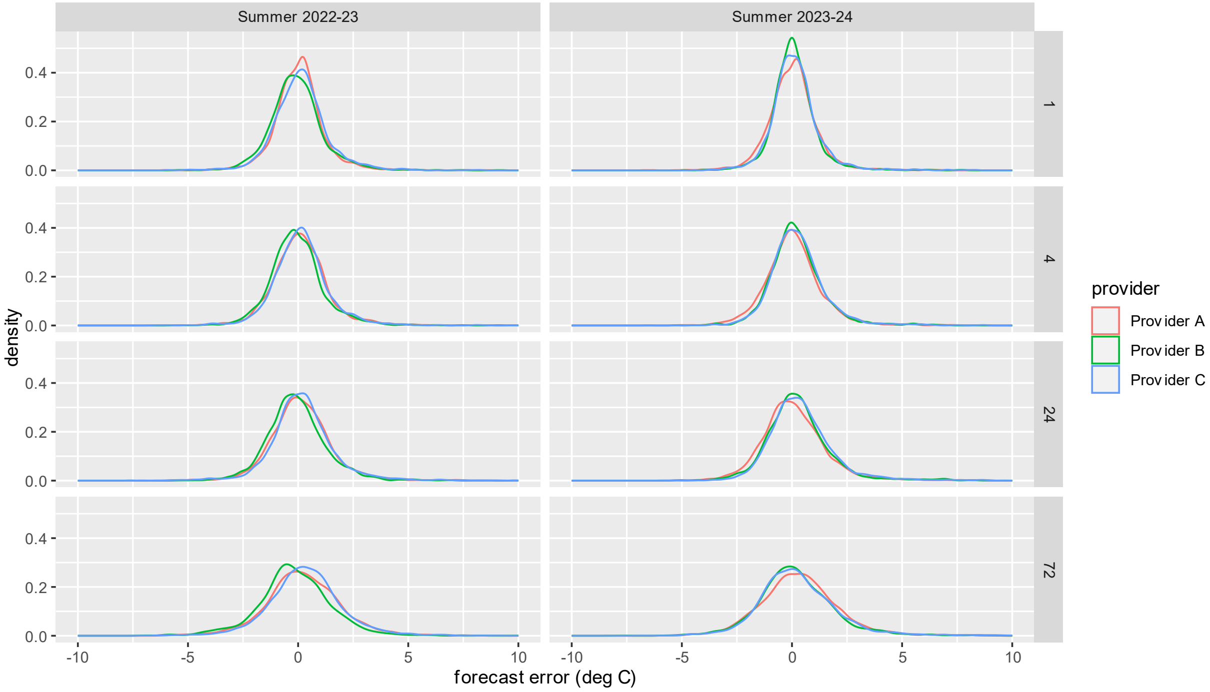
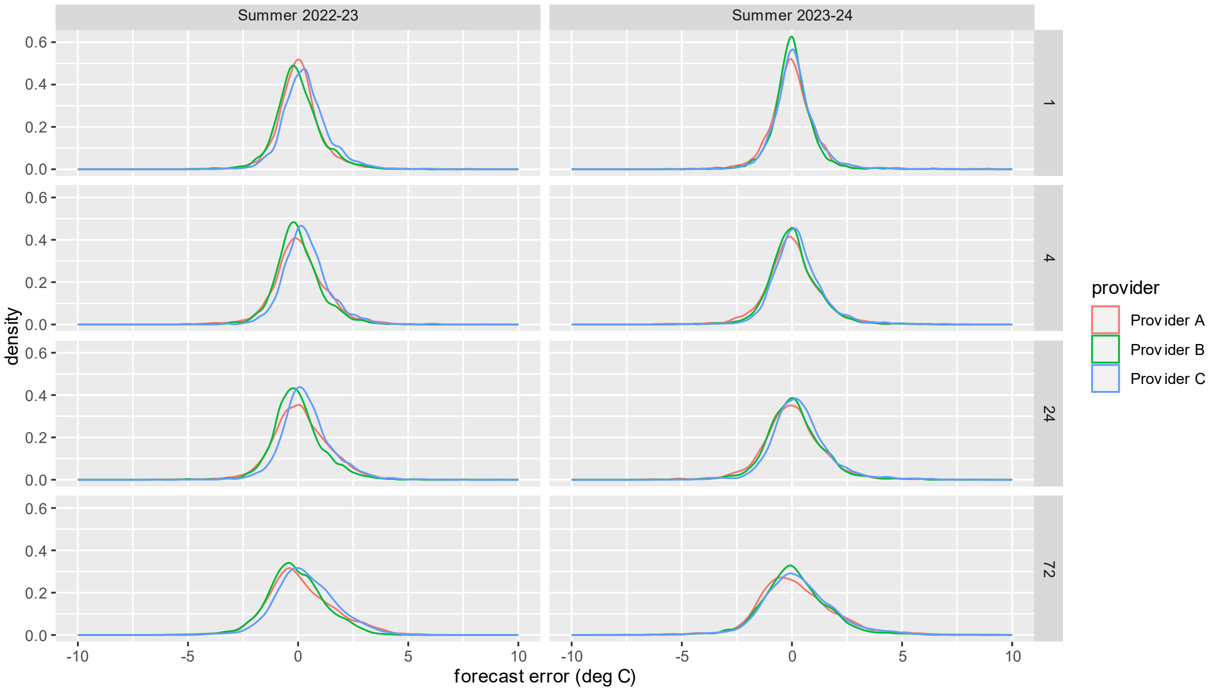
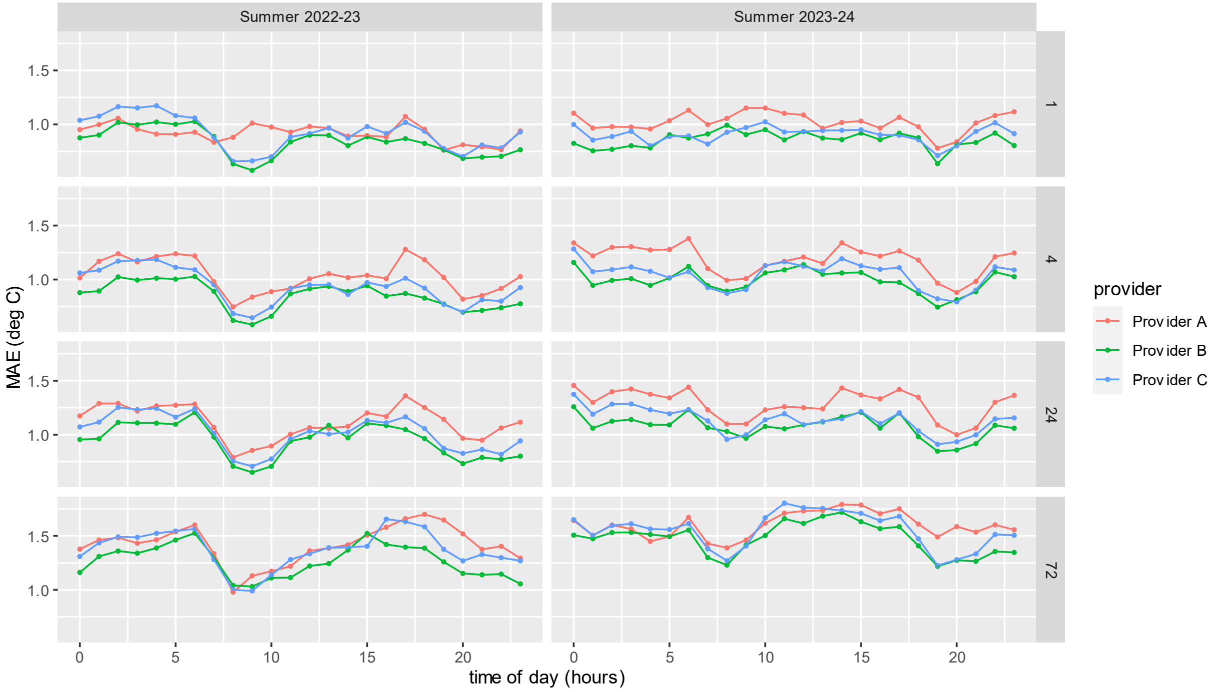



**Figure 38 Sydney AP, all summer temperatures 2022-23 and 2023-24, all time horizons**



# A2. Intraday MAE profiles

### Figure 39 Adelaide WT, intraday MAE profile, summer 2022-23 and 2023-24, all time horizons, all temperatures




### Figure 40 Archerfield AP, intraday MAE profile, summer 2022-23 and 2023-24, all time horizons, all temperatures

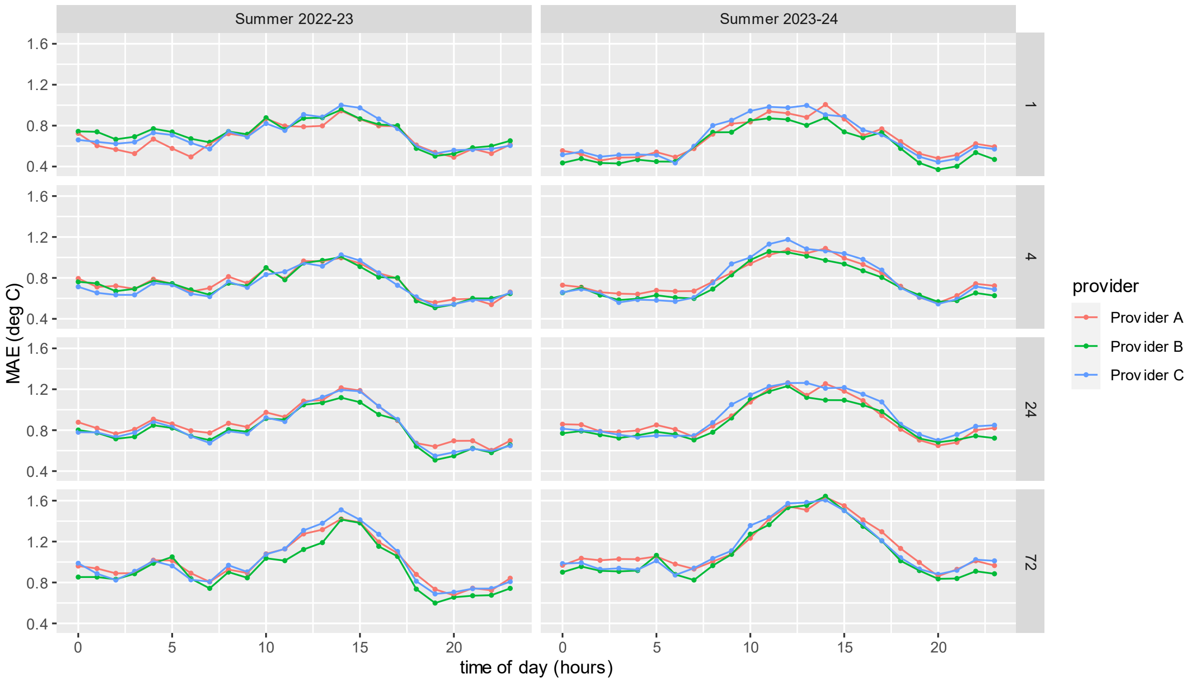


**Figure 41 Bankstown AP, intraday MAE profile, summer 2022-23 and 2023-24, all time horizons, all temperatures**

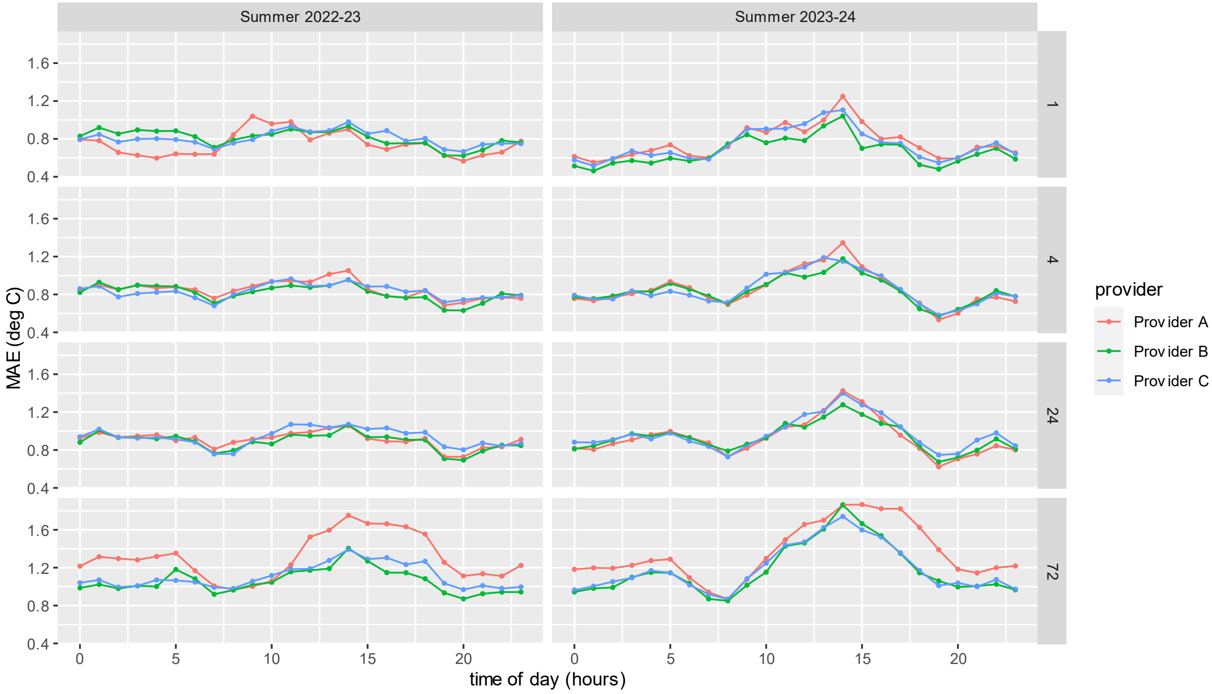



**Figure 42 Hobart AP, intraday MAE profile, summer 2022-23 and 2023-24, all time horizons, all temperatures**

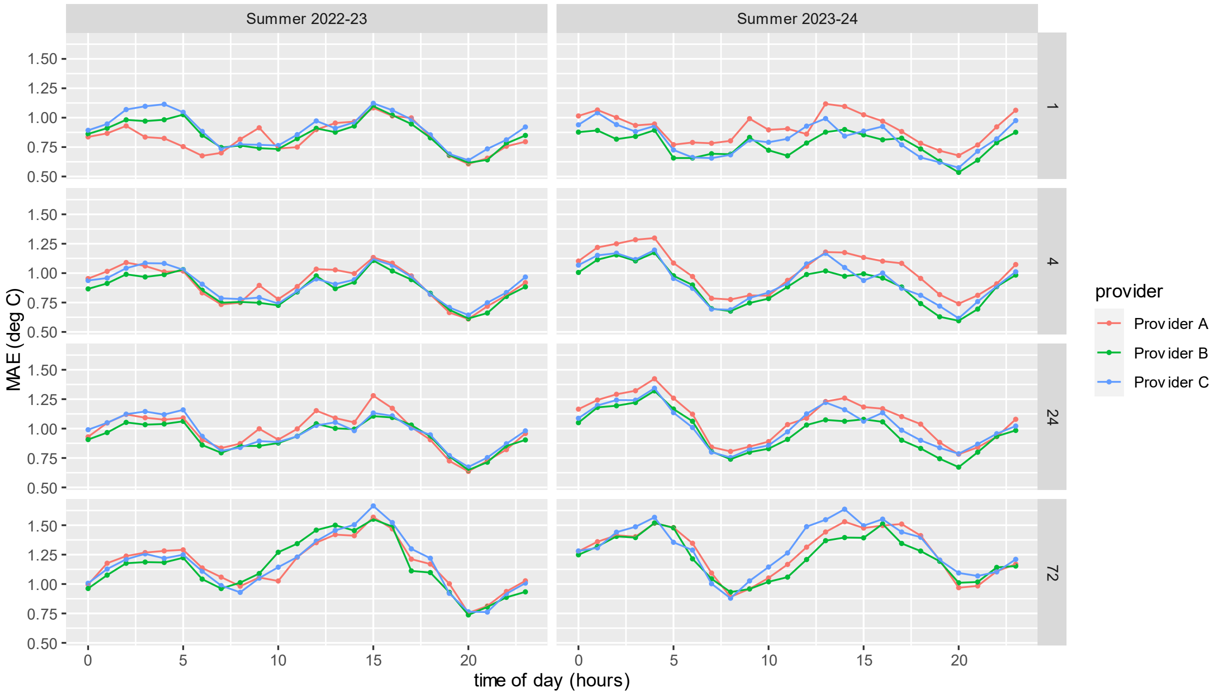


**Figure 43 Melbourne OP, intraday MAE profile, summer 2022-23 and 2023-24, all time horizons, all temperatures**

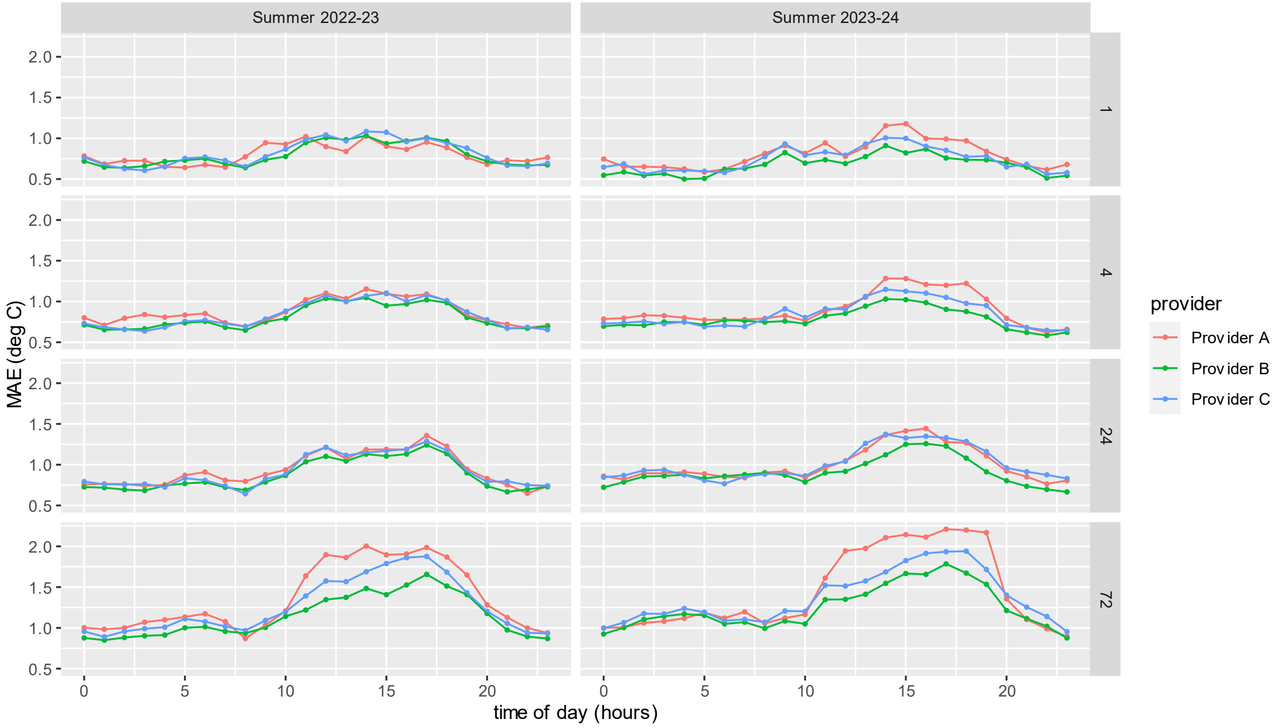



**Figure 44 Melbourne AP, intraday MAE profile, summer 2022-23 and 2023-24, all time horizons, all temperatures**

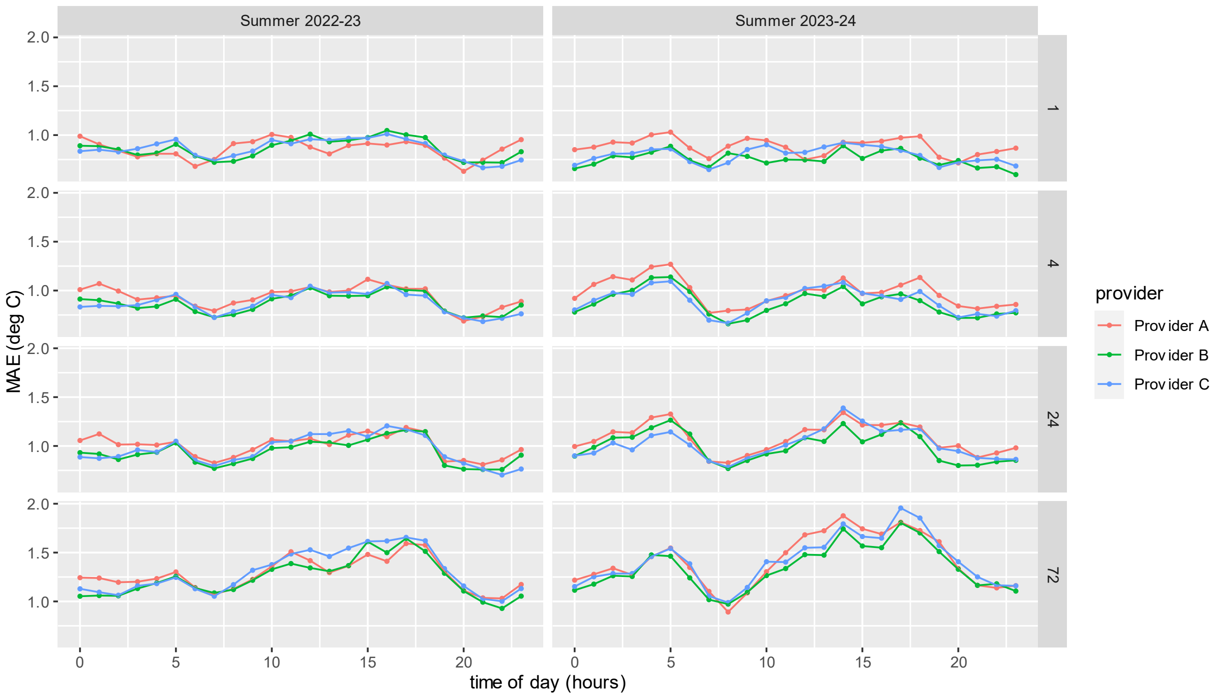


**Figure 45 Penrith Lakes, intraday MAE profile, summer 2022-23 and 2023-24, all time horizons, all temperatures**

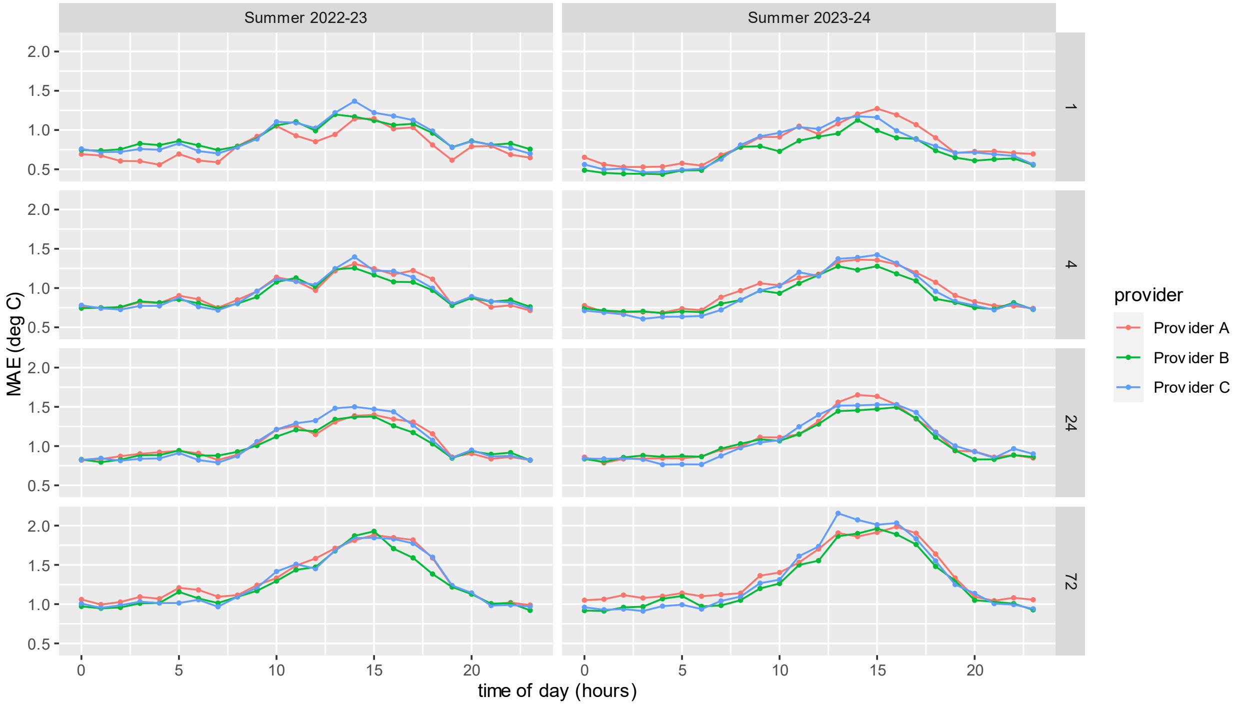
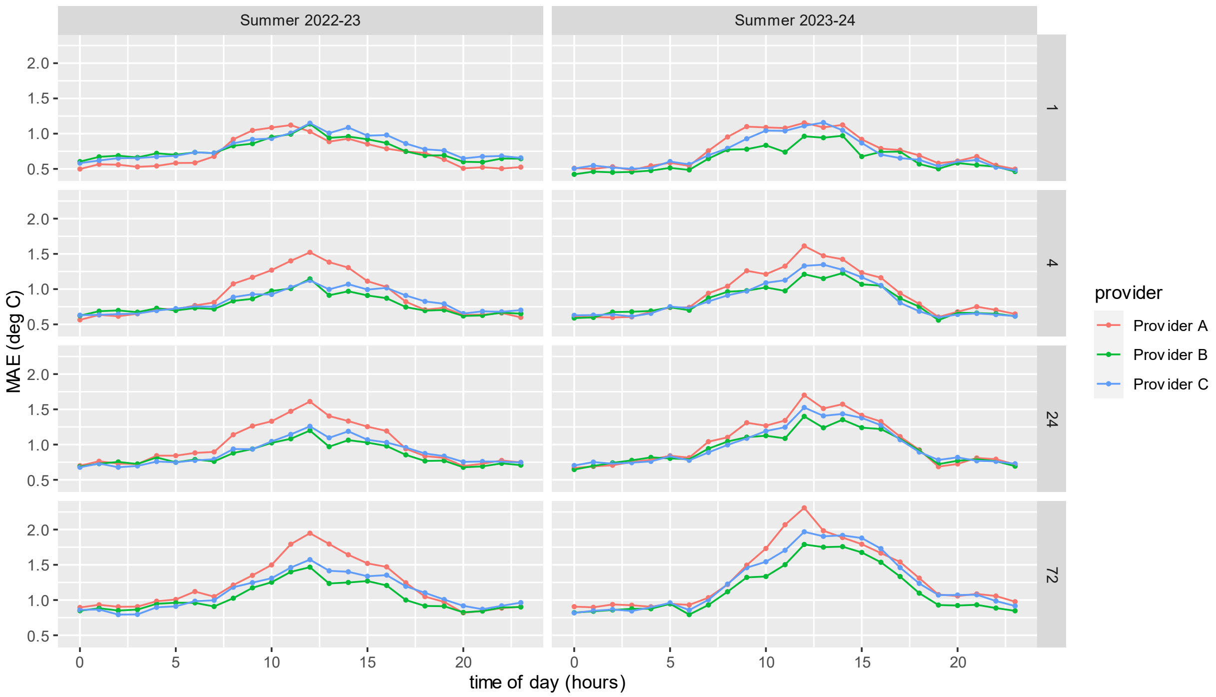



**Figure 46 Sydney AP, intraday MAE profile, summer 2022-23 and 2023-24, all time horizons, all temperatures**



# A3. Net count of forecast error direction

**Figure 47 Adelaide WT, net count of forecast error direction for the top 10% of days**

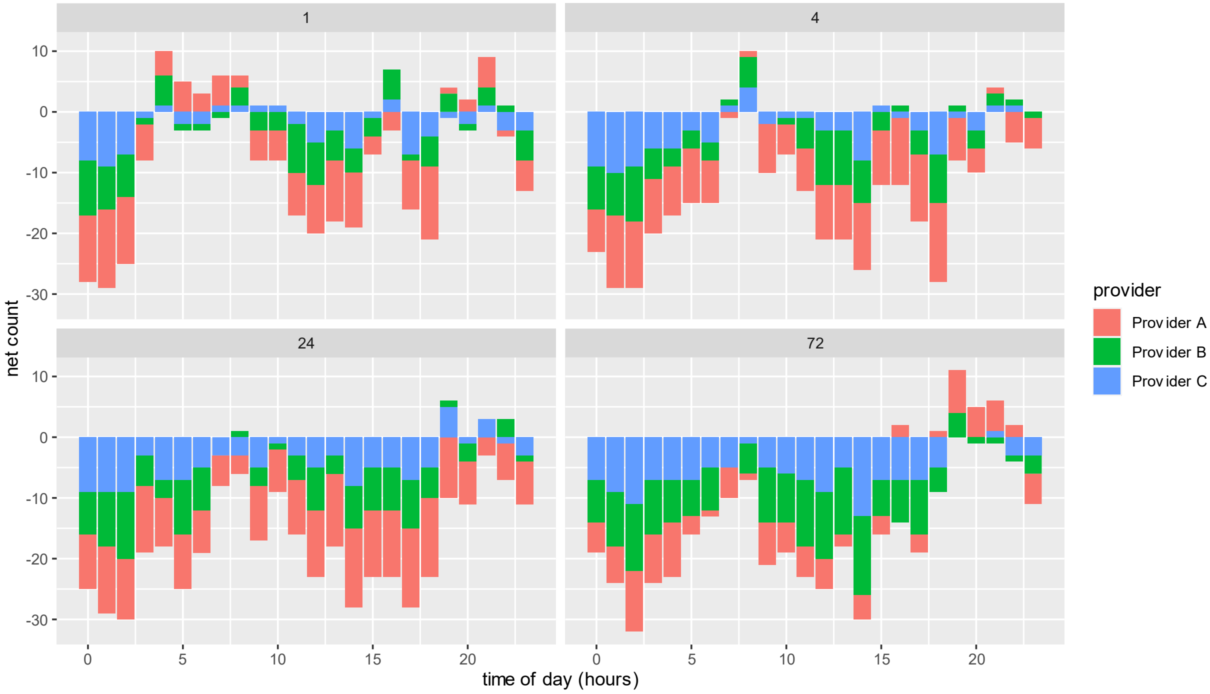



**Figure 48 Archerfield AP, net count of forecast error direction for the top 10% of days**

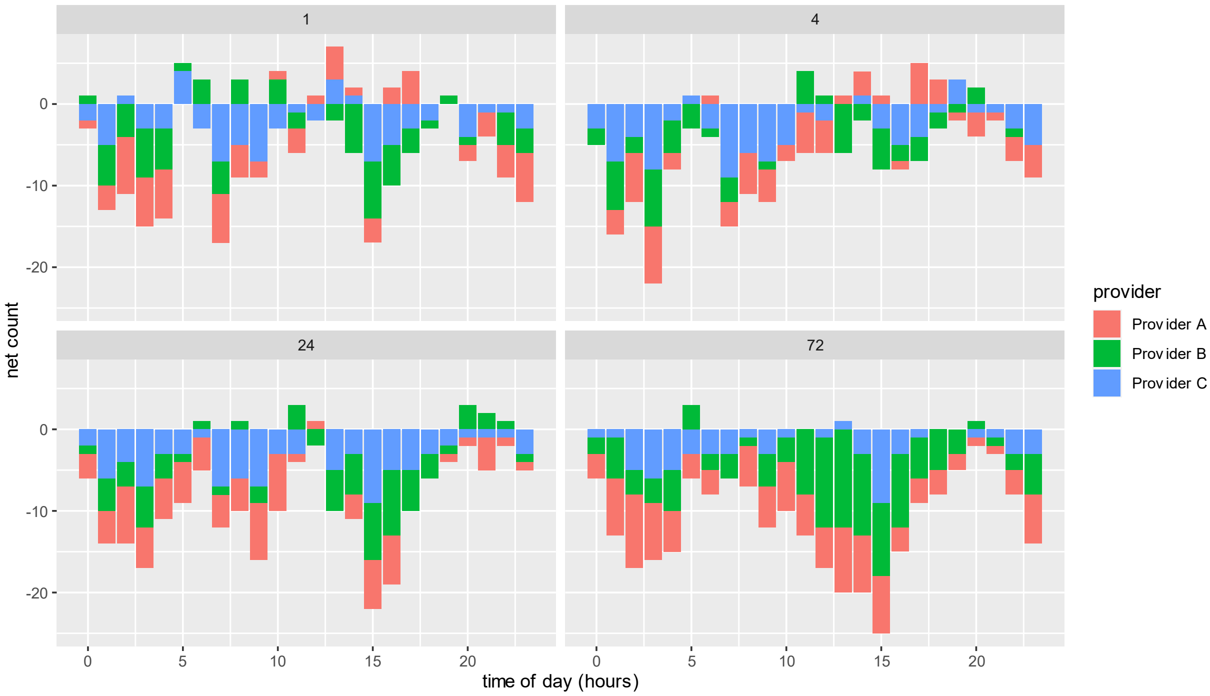


**Figure 49 Bankstown AP, net count of forecast error direction for the top 10% of days**


**Figure 50 Hobart AP, net count of forecast error direction for the top 10% of days**

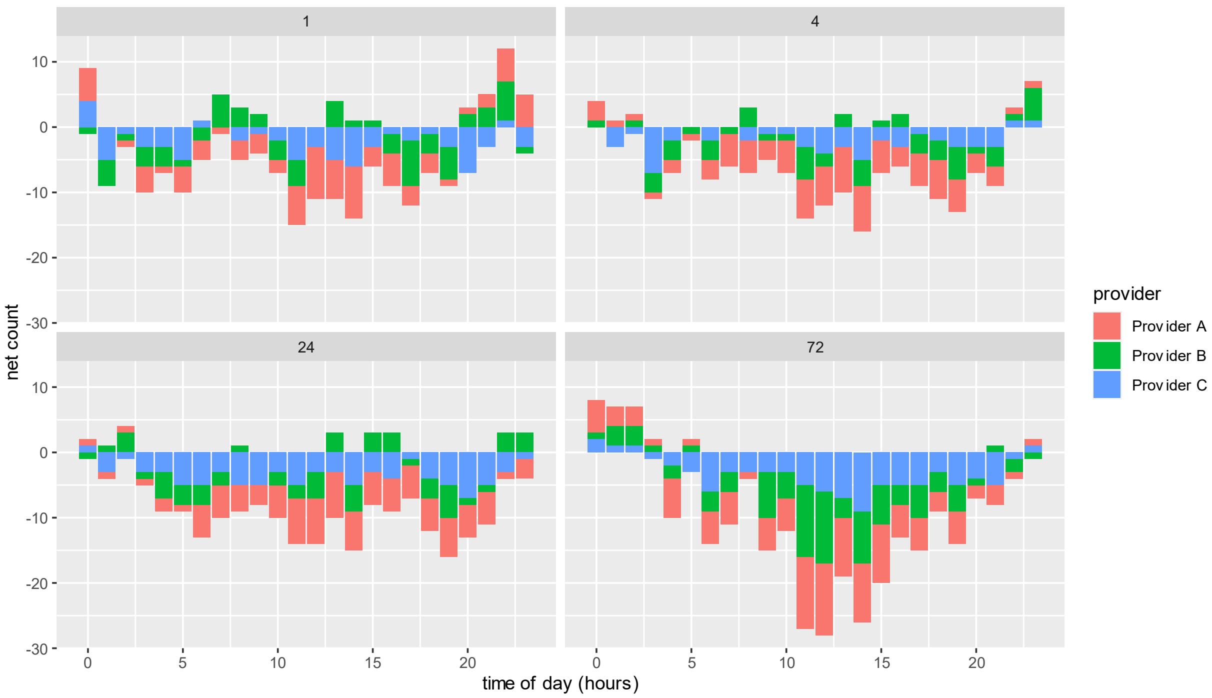


**Figure 51 Melbourne AP, net count of forecast error direction for the top 10% of days**

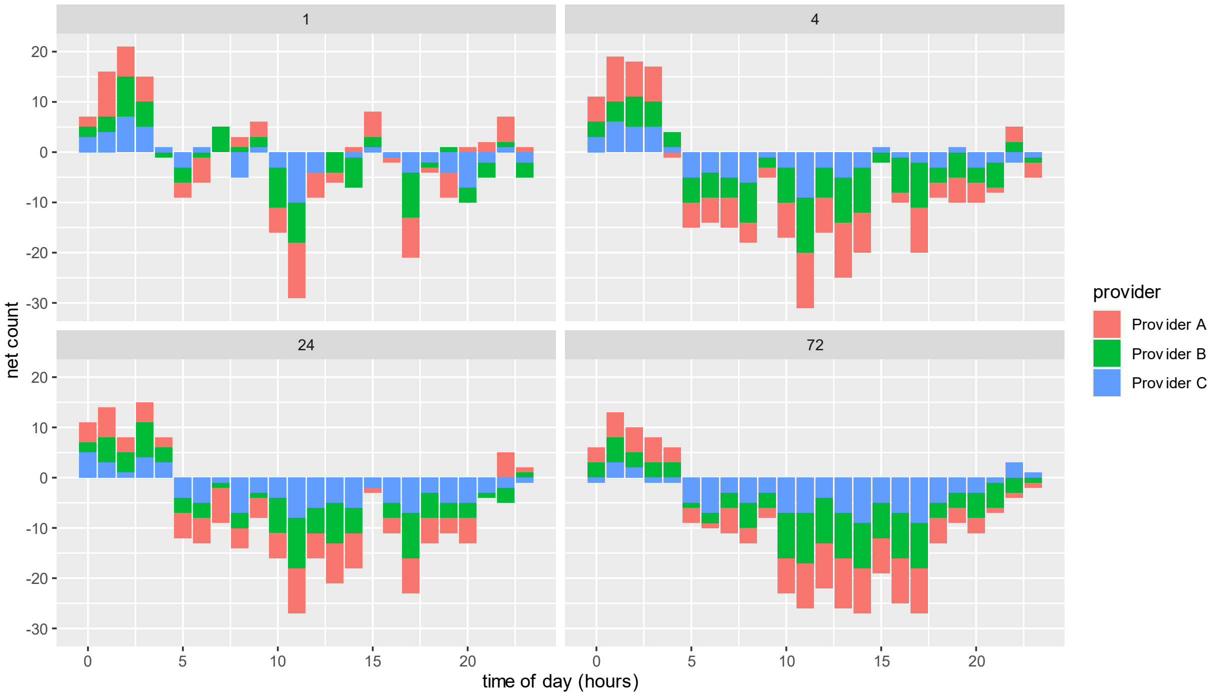
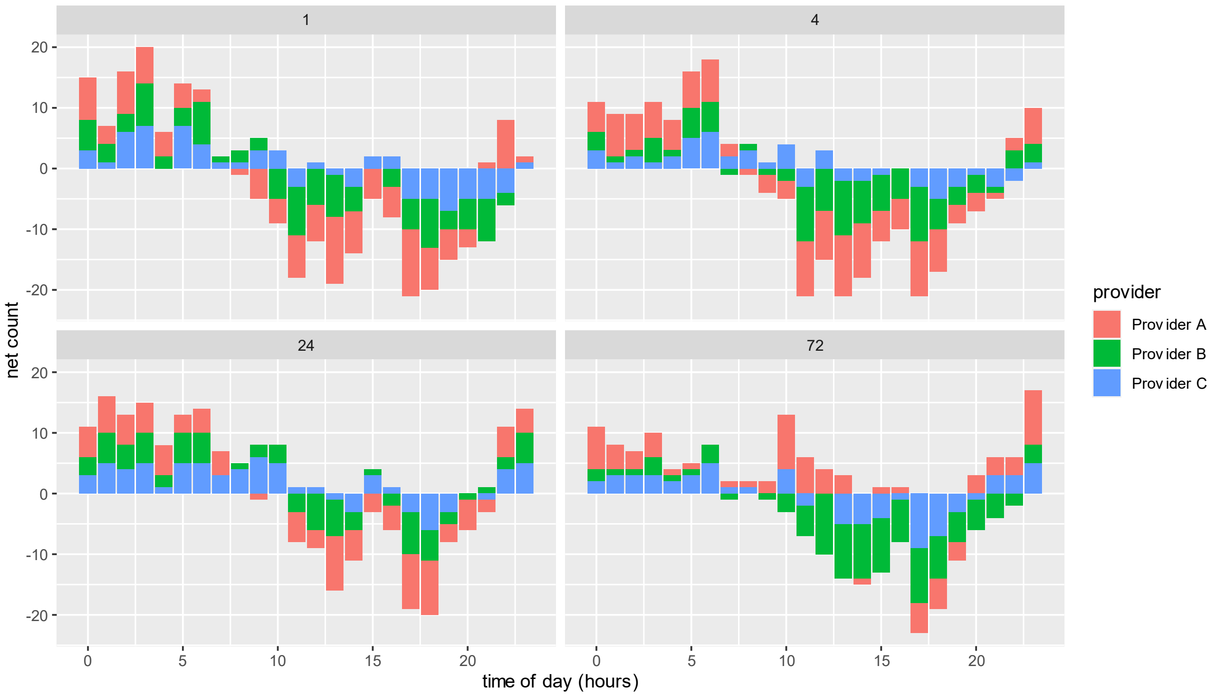
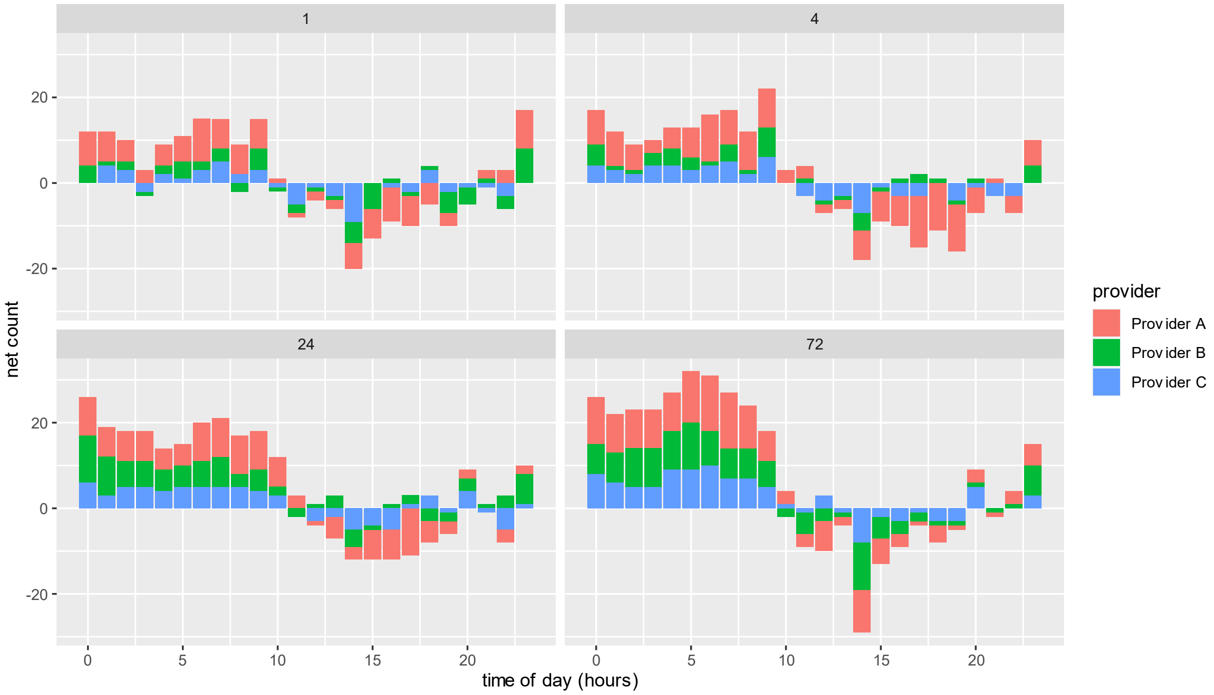



**Figure 52 Melbourne OP, net count of forecast error direction for the top 10% of days**



## Figure 53 Penrith Lakes, net count of forecast error direction for the top 10% of days




## Figure 54 Sydney AP, net count of forecast error direction for the top 10% of days